ECOPHYSIOLOGICAL AND TECHNOLOGICAL FACTORS INFLUENCING THE MANAGEMENT OF COGONGRASS (*IMPERATA CYLINDRICA*)

By

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PHYSIOLOGICAL AND TECHNOLOGICAL FACTORS AFFECTING THE CONTROL OF COGONGRASS (IMPERATA CYLINDRICA)

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Cogongrass (*Imperata cylindrica* (L.) Beauv.) is a problem weed throughout tropical and subtropical regions of the world, and in the southeastern United States has invaded planted forests, rangeland, reclaimed mined areas, roadsides, and natural ecosystems. Herbicides alone and in combination with tillage were evaluated in the greenhouse or field, on different soil types, and at different application times. Revegetation of cogongrass-infested land with desirable plant species after suppression of cogongrass was evaluated. Revegetation species included *Indigofera hirsuta* (L.), *Lolium perenne* (L.), *Paspalum notatum* Flugge, *Panicum virgatum* (L.)/*Chamaecrista fasciculata* (Michx.) Greene, or *Cynodon dactylon* (L.) Pers. Apical dominance in cogongrass rhizomes was studied by mechanically breaking dormancy of rhizome apices, and with applications of nitrogen and growth

regulators. The effects of light intensity on herbicide translocation and efficacy were evaluated using chlorophyll *a* fluorescence measurements, herbicide dose-response studies at different light levels, and ^{14}C-labelled herbicides. Autumn applications of glyphosate (2.24 kg/ha) and imazapyr (0.84 kg/ha) provided greater than 80% control of cogongrass whereas spring or summer applications provided less than 60% control 12 months after treatment (MAT). Discing alone provided only short-term control but 2 discings and split applications of imazapyr controlled cogongrass growth up to 96% 12 months after treatment. Growth of desirable species depended on tolerance to herbicides and soil type, and successfully displaced cogongrass in some areas. Axillary bud activity increased when the dominant apex was removed, by adding high concentrations of nitrogen, and by soaking apical rhizome segments in naptalam. Indole-3-acetic acid re-imposed dormancy of axillary buds in rhizomes where the apex had been removed. Glyphosate efficacy in greenhouse studies and chlorophyll *a* fluorescence in glyphosate treated plants were adversely affected by high light intensity, while imazapyr was relatively unaffected. Light intensity above the light compensation point of cogongrass did not affect glyphosate or imazapyr translocation into the root/rhizome.

CHAPTER 1
INTRODUCTION

Cogongrass (*Imperata cylindrica* (L.) Beauv.) is a serious pest throughout the tropical regions of the world and ranked as the seventh most troublesome weed worldwide (Holm et al., 1977). Cogongrass is a perennial, rhizomatous, C_4 grass which may reproduce from seed, but flowering has been reported as infrequent and generally occurs only after human disturbance or stress (Sajise, 1972), but in Florida occurs throughout the year (personal observation). The persistent and aggressive rhizomes of cogongrass are the main mechanisms for survival, local spread, and the chief reason cogongrass is difficult to control.

Cogongrass has developed into a severe weed problem in the southern gulf states (Dickens, 1974; Elmore, 1986). The weed cannot survive in areas where the ground is regularly cultivated, but thrives on roadways, pastures, mining areas, forest land, parks and other recreational areas. Cogongrass has little utility except for thatch, short-term forage production, and soil stabilization. It is an inferior forage for domesticated animals, creates a fire hazard

during dry months due to its high vegetative production, and is poor habitat for native wildlife. The establishment of other grass species into cogongrass, particularly desirable perennial grasses, is difficult because cogongrass has the ability to extract soil water from shallow soil layers. Cogongrass is able to invade areas that will not support other grasses due to its ability to tolerate a wide range of soil conditions. It frequently spreads over large areas and will exclude other grasses (Hubbard et al., 1944).

There were two points of known introduction into the United States. Cogongrass was inadvertently introduced in Alabama in 1912 as a packing material in boxes from Japan (Dickens, 1974; Tabor, 1949, 1952). It was intentionally introduced from the Philippines into Mississippi as a possible forage in 1921 (Hubbard et al., 1944; Dickens and Buchanan, 1971; Patterson et al., 1983; Tabor, 1949; Tabor, 1952). Later, forage trials were also carried out in Texas, Mississippi, Alabama and Florida. The Texas planting died out in the first year, probably due to cold temperatures (Hubbard et al., 1944). Points of introduction into Florida include Gainesville (University of Florida Experiment Station), Brooksville (USDA Plant Introduction Station), and Withlacoochee (Soil Conservation Service reclamation area) (Hall, 1983; Willard, 1988). Cattlemen took the grass from the Florida Experiment Station in about 1939 and within ten years more than 1,000 acres of cogongrass had been

established in central and northwest Florida (Dickens, 1974).

Inland spread of cogongrass to cleared forest from coastal areas in Asia appeared to be by seed, primarily along rights-of-way bordering highways and railroads (Hubbard et al., 1944; Wilcut et al., 1988a). Cogongrass distribution and spread in Alabama from 1973 to 1985 appeared to have been due to seed being blown by north-easterly prevailing winds from the Gulf of Mexico along rights-of-way bordering Interstate 65 (Wilcut et al., 1988a). This agrees with the observation of Hubbard et al. (1944) in Asia concerning spread of cogongrass from coastal to inland areas. The pattern of distribution of cogongrass outside the southeastern counties of Mississippi indicates that it was established sporadically, possibly through windspread seed or by rhizomes being carried in soil during road construction (Patterson and McWhorter, 1983). Willard (1988) speculated that spread in Florida has been due to movement of soil contaminated with the rhizomes.

Pendleton in 1948 stated that steps should be taken at once to completely eradicate this noxious weed from the western hemisphere, and warned that the hazard of cogongrass as a weed species far outweighed any benefit it could offer as a forage.

Taxonomy and Distribution

Imperata is a genus of the tribe *Andropogoneae* subtribe *Saccharine*. Five taxonomic varieties have been recognized by Santiago (1980), but Clayton and Renvoize (1982) reported that these varieties intergrade and true distinctions cannot be made. Clayton and Renvoize stated that varietal classification should be ignored while recognizing that imperfectly separable geographical variants exist.

Morphology and Biology

Cogongrass is a perennial, rhizomatous, C_4 grass and may reproduce from seed and rhizomes. The plant is stemless, growing in loose to compact tufts with slender, flat, linear-lanceolate leaves from the rhizomes. The leaves are 1 to 2 cm wide with prominent white midribs which are slightly off center. The leaf blades and sheath may be 15 to 120 cm long with narrow, sharp, hard tips. Stomata can be found on both surfaces (Hubbard et al., 1944).

The plant has a fibrous root system and rhizomes which are long, white, tough and scaly with very short internodes. The branched rhizomes form a dense mat able to exclude most other vegetation. The sharp apical ends of the rhizomes may grow through the roots of other plants (Boonitee and Ritdhit, 1984; Eussen and Soerjani, 1975). Rhizome development starts between the third and fourth leaf stage of young plants. Early rhizome growth is plagiotropic, or vertical. Growth by the fifth leaf stage becomes horizontal

and the rhizomes are covered by scale leaves (cataphylls). The tips of the rhizomes grow upward (negatively orthogeotropic) between the fifth and sixth leaf stage. A second generation shoot arises from the apical bud and rhizomes form from sub-apical buds. Most buds are located at the nodes in the apical region of the rhizome. Buds do not develop until the diageotropic rhizome growth stage. Likewise, root development does not start until this stage, with a fibrous system formed at the rhizome nodes. Second generation shoots and rhizomes form simultaneously on strong plants. In weaker plants the shoot forms first, while buds on the convex side form shoots much later or remain suppressed (Ayeni, 1985).

Regenerative capacity is positively correlated to increasing age, weight, length, thickness and number of visible buds (Ayeni, 1985). Young rhizomes are not capable of regenerating the species. Roots do not develop in these rhizomes, and roots are necessary for nutrient supply and subsequent accumulation of enzymes and growth substances for regeneration. Biomass of the rhizome, which increases with age, is likely a necessary component of regenerative capacity (Ayeni and Duke, 1985).

Seedheads are branched but compacted into a dense, white, fluffy, spikelike panicle 10-20 cm long (Holm et al., 1977). The seeds are small and are attached to a plume of long hairs which facilitates wind dispersal of up to 15

miles over open country (Hubbard et al., 1944). A single plant may produce as many as 3000 seeds, but flowering has been reported as rare, generally occurs only after human disturbance or stress, such as cold, burning, tillage, or mowing (Sajise, 1972). In Florida, cogongrass flowers frequently but sporadically (personal observation). Flowers produced in response to stress rarely produce seed (Eussen, 1980).

The persistent and aggressive rhizomes of cogongrass are reported to be the main mechanism for survival and spread. These rhizomes make cogongrass difficult to control. Eussen (1980) reported that rhizomes can give rise to 350 shoots in six weeks and can cover 4 m^2 in 11 weeks. Cogongrass has a low shoot to root/rhizome ratio, which contributes to its rapid regrowth after burning or cutting (Sajise, 1976). Rhizomes of plants found in the United States are very resistant to heat (either natural or artificial), but are susceptible to cold (Wilcut et al., 1988b). In Alabama, cogongrass rhizomes were able to survive winter temperatures of -14 C (Wilcut et al., 1988b), but were unable to survive winters in Mississippi when the temperature reached -8 C (Hubbard et al., 1944).

The flowers of *I. cylindrica* each have two stamens, distinguishing it from the native *I. brasiliensis* Trin. [Brazilian bladygrass, Brazilian satintail or silver plume] that has only one stamen per flower (Hubbard et al., 1944;

Patterson et al., 1980). *Imperata brasiliensis* is also sometimes referred to as cogongrass and ranges from Florida through the West Indies and from southern Mexico to Brazil (Hall, 1983). No cogongrass species have been reported in Louisiana, but *I. brasiliensis*, a closely related species has been collected in Louisiana (Wilcut et al., 1988b). Since the major distinguishing characteristic between cogongrass and Brazilian satintail is the number of stamens, it would appear probable that cogongrass is in Louisiana but has not been differentiated from Brazilian satintail. An additional danger from Brazilian satintail and cogongrass is the possibility of interspecific hybridization (Wilcut et al., 1988b).

Habitat

Stands of cogongrass in Asia are usually found on soils with low pH, fertility, and organic matter that are highly leached (Sajise, 1980). Cogongrass seems to grow best in relatively acidic soil (pH 4.7) (Wilcut et al., 1988a), but grows well on clay soils of pH 7.0 (personal observation). Cogongrass is able to establish monotypic stands due to its highly competitive ability on soil with the aforementioned conditions (Eussen and Wirjahardja, 1973). Cogongrass has been reported to retard growth, cause yellowing of leaves and die-back of crops leading to severe yield reductions (Hubbard et al., 1944; Soerjani, 1970). Plants which have been found to survive competition with cogongrass have a

deeper root system than that of cogongrass and/or a taller canopy (Eussen and Wirjahardja, 1973).

The mechanisms of cogongrass interference are not known. Both allelopathy and competition have been reported (Eussen, 1979). Cogongrass has been reported to compete for nutrients, light, and water, and cause physical injury (caused by rhizomes penetrating roots of other plants) (Boonitee and Ritdhit, 1984; Eussen and Soerjani, 1975; Jagoe, 1938). Reduced growth of rubber or other trees by cogongrass has been reported to be caused by allelopathy (Eussen, 1979).

Management of Cogongrass

Dean et al. (1988) studied herbicide combinations, in-tank mixtures, sequential herbicide combinations, and application methodology (ie. diluent volume and ropewick application) for long-term cogongrass control. Imazapyr (+/-)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imadazol-2-yl] and glyphosate [N-(phosphonomethyl) glycine] provided the best control and two applications of each increased control over a single application. In one experiment, dalapon (2,2-dichloroproprionic acid) provided additional control when used in sequence with imazapyr and glyphosate. Sulfometuron (2-[[[[(4,6-dimethyl-2-pyrimidinyl)amino]-carbonyl]amino] suflonyl]benzoic acid) had little activity on cogongrass. The effects of imazapyr and glyphosate were additive in activity on cogongrass, and,

for long-term control, multiple applications were necessary Willard et al.a, unpublished).

Fluazifop (Butyl (R)-2-{4-[[5-trifluoromethyl)-2-pyridinyl]oxy], glyphosate, and imazapyr were applied at two rates and control of cogongrass evaluated in savanna in Nigeria (Akobundu, 1993). Suppression of cogongrass was achieved with all herbicides that were applied in the season of growth, but regrowth occurred by 12 weeks after treatment (WAT). At 52 WAT, imazapyr at 1.0 to 1.5 kg/ha controlled cogongrass better than glyphosate at 3.6 kg/ha or fluazifop at 2.5 kg/ha. Imazapyr applied in 234 L/ha of diluent was more efficacious than when applied in 46 L/ha.

Boonsrirat et al. (1985) and Lee (1985) evaluated imazapyr and glyphosate under various conditions. Imazapyr was evaluated at rates of 0.4 to 1.0 kg/ha, in single or split treatments in 250 to 625 l/ha of diluent. Maximum control was achieved at 90 to 120 days after treatment (DAT) with necrosis progressing slowly. Chlorisis was not evident until 15 to 30 DAT. One application of 0.75 kg/ha of imazapyr provided the same control as a 40 day split application of imazapyr at 0.5 kg/ha. Imazapyr at 0.75 to 1.25 kg/ha performed as well as glyphosate under dry conditions, and better under wet conditions. Imazapyr 1.25 kg/ha controlled cogongrass for up to 120 days longer than glyphosate at 4.32 kg/ha. Glyphosate at 3.3, 6.7, and 10 kg/ha achieved 91, 96, and 99% kill of cogongrass,

respectively. The two highest rates caused decay of rhizomes, while rhizomes of plants treated at the lower rate appeared firm. Bud development of glyphosate treated plants was restricted to the apical nodes.

Glyphosate, dalapon, and paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) were evaluated for cogongrass control in field tests on highway median-areas in Mobile County, AL, in 1970 and 1971. In single application experiments, both dalapon and TCA provided initial control, but combining these two herbicides did not improve control. A combination of dalapon (8.3 kg/ha) and TCA (112 kg/ha) provided complete control in 1971 research. Efficacy of glyphosate and dalapon was equal when applied at equal rates. Five applications of paraquat provided the greatest reduction in shoot regrowth the following spring. Using split applications, lower rates with dalapon and amitrole provided equal control when compared to higher rates (Dickens and Buchanan, 1975).

Multiple ropewick and cloth applications of glyphosate or imazapyr have been reported to be effective for cogongrass control (Townson and Butler, 1990). Imazapyr at a concentration of 50% v/v applied twice provided maximum control. The concentration of glyphosate did not matter, although the concentration of glyphosate applied using a ropewick has been shown to influence the control of other perennial species. Cloth applications of glyphosate also

achieved complete kill of cogongrass foliage in a field study. In a greenhouse experiment, the dose of imazapyr required to prevent regrowth of cogongrass was six times less than that of glyphosate. Cloth-applied glyphosate showed visible phytotoxicity faster than rope-wick applications. As the dose of imazapyr increased, the activity of cloth-applied herbicide was greater than rope-wick applications. At the lowest application rate, the ropewick method was more effective. Increasing the concentration of glyphosate improved cogongrass control. This is in agreement with Buhler and Burnside (1983) who found that the activity of glyphosate increased as diluent volume decreased and concentration increased.

Timing has also been shown to influence the efficacy of herbicides on cogongrass (Lee, 1986). In a greenhouse study, dalapon at 8.0 kg/ha completely killed foliage at the one-leaf shoot stage, achieved partial kill at the 4-leaf stage, and killed old leaves, tips, and mid-regions of younger leaves. Glyphosate at 1.0 kg ai/ha achieved 75% kill of shoots at the 4- and 6- to 7-leaf stages. Dalapon and glyphosate caused decay of primary rhizomes after one month when applied at the 1-leaf stage. At the 4-leaf stage, dalapon caused decay of only a few secondary buds and rhizomes, whereas glyphosate caused the decay of primary rhizomes in fifty percent of the treated plants. At the 6- to 7-leaf stage, dalapon had little effect on primary,

secondary, or tertiary rhizomes. Glyphosate turned primary rhizomes black and soft; secondary rhizomes decayed at the shoot apices; and tertiary rhizomes completely decayed when applied at the 6- to 7-leaf stage.

Apical Dominance

Understanding patterns of growth and source/sink relationships in development of perennials is needed for a comprehensive approach to perennial weed management. Apical dominance, size, and age of rhizomes influence the dormancy of nodes and subsequent survival of rhizomes after systemic herbicide applications. The term correlative inhibition has been used to describe the inhibiting influence of growth of one part of a plant on another (Goebel, 1900; Smith and Rogan, 1980). Young rhizomes of quackgrass (*Agropyron repens* (L.)) demonstrate strong polar growth as the rhizome develops. As the rhizome increases in length, the apex becomes less dominant, allowing buds toward the base of the rhizome to stop being affected by inhibitors and begin growth. This system of growth and development allows rhizomatous species such as quackgrass and cogongrass to escape control by herbicides. Systemic, phloem mobile herbicides move with assimilates to actively growing plant parts. However, buds inhibited by a nearby, dominant bud, necessarily have lower sink activity which may contribute to sub-lethal herbicide concentration at these nodes.

Two theories have been proposed to explain apical

dominance and correlative inhibition. One is control by indole-3-acetic acid (auxin). Exogenously applied auxin has been shown to substitute for the shoot apex in maintaining apical dominance (Leakey et al., 1975). A second theory espouses the role of nutritional differences among plant parts as the controlling factor in apical dominance. Nitrogen and carbohydrate supply are limited in basal nodes by the much stronger sink at the apex (McIntyre, 1990). These theories are not necessarily mutually exclusive. Although critically important to understanding herbicide movement in perennial weeds, the mechanism controlling axillary bud dormancy in rhizomes has not been unequivocally determined.

Wilcut et al. (1988a) compared the growth of cogongrass, torpedograss (*Panicum repens (L.)*), and johnsongrass (*Sorghum halapense (L.)*) and determined that the spread of cogongrass in local areas is limited by a lack of axillary bud formation on most of the rhizome. In these studies, this growth characteristic reduced the ability of the rhizomes to send up new shoots and only a rapid spread of rhizomes was achieved. The axillary buds of torpedograss and johnsongrass are active along the entire length of the rhizome, which upon fragmentation produce aerial shoots. Removal of the apical 2 cm of a 10 cm long apical rhizome section of the three species resulted in a proliferation of shoot growth from torpedograss and johnsongrass, but

generally prevented shoot regrowth in cogongrass. This agrees with Peng (1984), who reported little to no sprouting from cogongrass rhizome segments, but disagrees with Hubbard et al. (1944), who reported shoots produced from even small rhizome segments. Wilcut et al. (1988a) also report that cogongrass is sensitive to burial, unable to send up shoots from deeper than 8 cm. Torpedograss and johnsongrass were able to produce shoots from as deep as 16 cm.

Herbicide Absorption and Translocation

Glyphosate absorption, translocation, and exudation were studied to determine the effects on rhizome bud kill of two cogongrass biotypes from Sumatra and Florida (Sriyani, 1992). The biotypes were equal in amounts of ^{14}C-glyphosate absorbed, but more ^{14}C-glyphosate was translocated to the Florida rhizomes seven days after treatment. Glyphosate reduced bud-sprouting in both biotypes at 0.5 and 1.0 kg/ha, with the Sumatra biotype bud-sprouting more adversely affected at 0.5 kg/ha. The pattern of bud-sprouting after treatment indicated that cogongrass bud meristems are regulated by apical dominance. Apical bud kill from herbicide accumulation in the rhizome tip area forced axillary buds to sprout.

Uptake and translocation of ring-labelled ^{14}C-imazapyr in cogongrass decreased with increasing concentration of the herbicide, with the reverse true for glyphosate in both the greenhouse and field (Townson and Butler, 1990). More

radiolabel was absorbed from the basal area of the leaf than from either the middle or tip of the leaf for both imazapyr and glyphosate. Position of application did not affect translocation of either herbicide. Recovery of applied radiolabelled imazapyr 72 h after application was 30% from the rhizomes and 18% from the shoots. For glyphosate, 21% was recovered from the rhizomes and 10% from the shoots. Four hours after application of ^{14}C-glufosinate-ammonium to cogongrass, 53.7% of the radioactivity was found in the treated leaves, and 0.5% was found in rhizomes (Townson and Butler, 1990). After one day, the amount in rhizomes had dropped to 0.2%.

Ring-labelled ^{14}C-imazapyr was used to determine the influence of monoionic linear alcohol surfactants (2, 7, or 20 ethylene oxide [EO]) on uptake and translocation in cogongrass (Townson and Price, 1987). Phytotoxic action was reduced by high concentrations of imazapyr and/or surfactant. Uptake and translocation of radiolabelled herbicide was positively correlated with visual phytotoxicity. The EO equivalents of the surfactant influenced movement directly. The ratio of surfactant to active ingredient of the herbicide was also shown to be important for maximum biological activity. A formulation containing 7 to 12 EO residues at a 0.5 to 1.0% w/v concentration with the minimum lethal dose of imazapyr in very low spray volume applications has the potential for

"excellent activity." However, low diluent volume may have led to poor coverage and consequently reduced activity.

Shaner (1988) determined the absorption and translocation of imazapyr and its influence on water usage and growth in cogongrass. Imazapyr, a herbicide that interferes with acetohydroxyacid synthase, is quickly absorbed by leaves and translocated out of the leaf, with translocation peaking at 4 days and dropping rapidly thereafter. This drop in translocation was attributed to death of growing points and subsequent reduction of photosynthate sink strength. Leakage of up to 13% of labelled herbicide into the soil was observed, possibly due to death of underground tissue. Imazapyr caused leaf growth to stop within one day, although leaves remained green for a minimum of one week. Reduction of plant growth and inhibition of transpiration in treated plants decreased water use within 48 hours.

Rhizome length and growth stage effects on ^{14}C-methyl-labelled glyphosate translocation in johnsongrass were evaluated by Lolas and Coble (1980). Six days after application, ^{14}C was determined to be in the following tissues: 15-37% remained on the leaf, 6-10% was absorbed, but remained in the treated area, 18-47% was absorbed into the other two treated leaves, and 2-8% was translocated to the rhizomes. The relative concentration of ^{14}C (dpm/g fresh weight) remained constant in the rhizomes. Long rhizomes or

rhizomes of plants at the seedhead growth stage accumulated as much ^{14}C per gram fresh weight as short rhizomes or rhizomes of plants not at the seedhead stage. This may indicate that long rhizomes or rhizomes of rammets close to the seedhead stage were stronger sinks than short rhizomes or rhizomes of plants at an earlier growth stage.

Glyphosate distribution in relation to sucrose accumulation was studied in quackgrass with labelled CO_2 by Shieh et al. (1993). Glyphosate movement closely paralleled sucrose movement, and sucrose and glyphosate accumulations were high in the tip and decreased toward the base of quackgrass rhizomes. However, sink activity was variable and not easily predicted in buds of different rhizomes. Low sink activity and low concentrations of glyphosate were consistently detected in older buds. The authors' conclusion was that when active buds were killed by glyphosate, those with a sublethal concentration of glyphosate were released from dormancy.

Imazapyr and glyphosate are effective herbicides for cogongrass control. However, repeat applications are needed to inhibit regrowth from the extensive rhizome system. Both herbicides are readily absorbed and translocated throughout the plant. However, the herbicides have different mechanisms of action. Imazapyr is in the imidazolinone herbicide family and works by binding at the aceto-lactate synthase enzyme thereby preventing synthesis of the

branched-chain amino acids leucine, isoleucine, and glycine (Shaner and O'Connor, 1991). Imazapyr had little or no effect on respiration, photosynthesis, or lipid or protein synthesis. Imazapyr did suppress DNA synthesis, and the imidazolinones in general increase the levels of free amino acids. Neutral sugar levels in corn leaves also increased in corn plants with 24 h of treatment, likely due to continuation of photosynthesis, while transport of photosynthate out of leaves was inhibited. Applied to cogongrass, imazapyr inhibited leaf elongation within 1 day of treatment and maximum translocation occurred within 4 days (Shaner, 1988).

Glyphosate inhibits activity of 5-enolpyruvyl shikimic acid-3-phosphate synthase, thereby preventing synthesis of the aromatic amino acids phenylalanine, tryptophan, and tyrosine (Duke, 1985). Glyphosate has numerous other direct or indirect effects on plants. Glyphosate reduced variable fluorescence under light conditions within 4 h, but not until 44 h after an initial 24 h dark period followed by alternating 8 h light/8 h dark periods (Madsen et al., 1995). Chlorophyll *a* and *b* content was reduced by 24 h in clover and lucerne by 0.15, 1.5, and 15 mM glyphosate concentations, and carotenoid pigments were also affected (Munoz-Rueda et al., 1986). Photosystem I and II electron transport was affected 7 days after treatment at all concentrations and stomatal conductance was lowered 7 DAT

for both species. A 17 mM concentration of glyphosate immediately reduced ribulose bisphosaphate (RuBP) levels in sugar beet (*Beta vulgaris* (L.)) leaves, and phosphoglyceric acid levels dropped at 2 h after treatment. The rate of photosynthesis followed RuBP decline (Servaites et al., 1987). Shieh et al. (1991) reported that net carbon exchange (NCE) decreased within 1 h after glyphosate application. Geiger and Bestman (1990) reported that glyphosate limits its own phloem transport by limiting CO_2 fixation, by inhibiting starch synthesis and changing normal carbon allocation pathways. Moosavi-nia and Dore (1979) reported that glyphosate was more efficacious on cogongrass at reduced light intensities, and attributed this to leaf morphological changes.

Total Nonstructural Carbohydrates

Nonstructural carbohydrates of a plant are reserves available for growth and respiration. The amount of total nonstructural carbohydrates (TNC) in a plant is influenced by environment, taxonomy, anatomy, stress, phenology, and management. Diurnal fluctuations in TNC have been documented to occur (Greenfield and Smith, 1974). An increase in total sugars and starch occurred in switchgrass (*Panicum virgatum* L.) between 6 am and 6 pm, followed by a drop until midnight. From 6 am to midnight, basal sheaths and internodes (i.e. storage parts) accumulated starch (Greenfield and Smith, 1974). Nonstuctural carbohydrate

content of perennial plant parts may be used to determine translocation of photosynthate. If herbicides move with the translocation stream, determination of photosynthetic product movement may aid in timing of herbicide application (Potter et al., 1986). Environmental conditions that promote movement of assimilate to the roots and rhizomes also favor herbicide translocation to these parts (Harker and Dekker, 1988). Total nonstructural carbohydrate concentration in roots of prickly-pear was lowest on 1 July and increased after fruit drop in September (Potter et al., 1986). Replenishment occurred from early autumn to midwinter. The authors suggested that photosynthetic rates may be high in autumn through midwinter, and that the most effective time for herbicide application would be August through March.

Translocation in quackgrass of ^{14}C-labelled sucrose, glyphosate, sethoxydim, cloproxydim, fluazifop, haloxyfop, and quizalofop was evaluated, with special attention to rhizomes (Harker and Dekker, 1988). More sucrose moved to the rhizomes more than herbicides, with the movement of glyphosate to rhizomes greater than the other herbicides. In general, ^{14}C translocation to shoots from the treated leaf (first fully expanded leaf from the primary shoot) increased with increasing temperature. Decreased rhizome growth and an increase in the number of dormant buds with high temperatures diminished sink activity in the rhizomes and

consequently reduced translocation to the rhizomes. Quackgrass rhizome bud growth was favored by the moderate temperature regime. Haloxyfop was the most inhibitory herbicide to rhizome bud growth. Higher temperature increased translocation of herbicide from the treated leaf to shoots. Herbicides were not distributed as evenly as sucrose.

CHAPTER 2

EFFICACY AND TIMING OF APPLICATION OF SELECTED HERBICIDES FOR THE CONTROL OF COGONGRASS UNDER GREENHOUSE AND FIELD CONDITIONS

Introduction

Cogongrass (*Imperata cylindrica* (L.) Beauv.) is a serious pest throughout tropical and sub-tropical regions of the world (Holm et al. 1977). Cogongrass was introduced to the gulf region of the United States by accident and as a potential forage (Tabor, 1952). It is a perennial, rhizomatous, C_4 grass, reproducing both vegetatively and via seed (Sajise, 1972).

Control of cogongrass has proven difficult, and evaluation of herbicides for the control of cogongrass has been limited in scope. Cogongrass is not a widespread problem in the United States nor is it a problem in most cropping situations. Therefore, industry has had no impetus to develop herbicides for cogongrass control and the previous research has concentrated on two or three herbicides. Timing of herbicide application to achieve maximum efficacy has been evaluated for other species (Lym and Messersmith, 1991; Shaw and Mack, 1991; Smith et al., 1993), but has not been thoroughly investigated for the control of cogongrass. Herbicide screening studies in

greenhouse conditions are efficient and economical, but evaluation of results may not be applicable to the field. Therefore, the objectives of these studies were 1) to establish the best methodology for evaluation of herbicide efficacy under greenhouse conditions, 2) to determine the activity of various herbicides for the control of cogongrass in both greenhouse and field situations, and 3) to determine the optimal timing of glyphosate application to achieve maximum control of cogongrass.

Fluazifop, glyphosate, and imazapyr were applied at two rates each and control of cogongrass evaluated on savanna in Nigeria (Akobundu, 1993). Suppression of cogongrass was achieved with all herbicides in the season of application, but regrowth occurred by 12 weeks after treatment (WAT). At 52 WAT, imazapyr at 1.0 to 1.5 kg/ha controlled cogongrass better than glyphosate at 3.6 kg/ha or fluazifop at 2.5 kg/ha. Lee (1985) reported 91, 96, and 99% kill in a field study with glyphosate at 3.3, 6.7, and 10 kg/ha, respectively. Willard et al. (unpublished a) reported that imazapyr provided better control than glyphosate or sulfometuron, and that tank-mixes of glyphosate and imazapyr provided similar control of cogongrass regardless of rate combination. Glyphosate (3.4 kg/ha) and imazapyr (0.8 kg/ha) reduced shoot and rhizome biomass up to 2 yr after application, but greater than 80% reduction of rhizomes was achieved only when dalapon, glyphosate, or imazapyr were

used in combination with 2 discings (Willard et al., unpublished b). Timing of herbicide application may also be important for maximum efficacy. Fall treatments of glyphosate provided greater control of cogongrass than spring or summer treatments in Florida (Tanner et al., 1992). Late-season herbicide applications have increased control in other species including leafy spurge (*Euphorbia esula* L.) (Lym and Messersmith, 1991), redvine (*Brunnichia ovata* L.) (Shaw and Mack, 1991), and torpedograss (*Panicum repens* L.) (Smith et al., 1993).

Numerous herbicides have recently been developed that may have potential for cogongrass management programs, but which have not been properly evaluated. Greenhouse studies offer a means of evaluating many herbicides in a timely fashion, under highly controlled conditions and at a reduction in cost relative to field research. However, greenhouse grown plants are often more sensitive to herbicides than field grown plants. Plants grown under artificial conditions generally have a thin leaf cuticle, are not stressed in any way, and may become pot-bound. Consequently, evaluation of the influence of growth stage and time of evaluation on efficacy is necessary. The studies reported herein were designed to address the problems of evaluating numerous herbicides under controlled and natural field conditions, and to determine the optimal timing of herbicide application for maximum, long-term

control of cogongrass.

Materials and Methods

Greenhouse herbicide methodology. Cogongrass plants for all greenhouse studies were propagated from 1-node rhizome segments that had produced a single shoot. All rhizomes were collected from the same, mature stand of cogongrass in Gainesville, FL. The optimal stage of cogongrass development for evaluating glyphosate efficacy was determined by planting rhizome segments at 3 week intervals. When the earliest-planted segments were 18 weeks old, glyphosate was applied to all plants (ranging in age from 3 to 18 weeks) at 0.0, 0.28, 0.56, 1.12, and 2.24 kg/ha. Treated shoot tissue was removed 2 weeks after treatment (WAT). Regrown shoots and rhizomes were harvested 7 WAT, dried in a forced air drier at 30 C for 72 h and weights recorded.

Optimal time for final evaluation was determined by applying glyphosate to 8-week-old cogongrass plants, removing shoot growth 2 WAT, and determining shoot and rhizome dry weight at 5, 7, 11, and 15 WAT.

Greenhouse herbicide evaluation. Herbicides (one concentration) included in the initial evaluation study were fenoxaprop ((±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid), fluazifop, glufosinate (2-amino-4-(hydroxymethylphosphinyl)butanoic acid), glyphosate, imazameth, imazapyr, imazaquin (2-[4,5-

dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinoline carboxylic acid), imazethapyr, metsulfuron, nicosulfuron, primisulfuron (2-[[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl]amino]carbonyl] amino] sulfonyl]benzoic acid), quinclorac (3,7-dichloro-8-quinoline carboxylic acid), quizalofop, sethoxydim (2-[1-(ethoxyimino)butyl]5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one-2-(2,4-dichlorophenoxy)ethyl hydrogen sulfate), sulfometuron, sulfosate, and vernolate (*S*-propyl dipropylcarbamothioate). Herbicide rates used in these experiments were chosen based on label recommendations and from information obtained from a review of literature. The most effective herbicides were then evaluated at multiple rates, applied to either soil or foliage, and the I_{50} concentration (concentration of herbicide required to inhibit growth 50%) calculated using the linear regression equation. Confidence intervals were calculated for the I_{50} values (Draper and Smith, 1981). For soil-applied treatments, two node rhizomes were grown in 4 L pots to allow for rhizome development, and the foliage removed at soil level. The herbicides were applied to the soil surface followed by approximately 1 cm of surface watering.

Representative plants were harvested at the time of treatment and the rhizome biomass was determined. The average rhizome dry weight of plants at treatment time was then subtracted from the final rhizome dry weights to

account for the weight of dead tissue. Thus, plant responses were based on growth during the treatment period.

Herbicides for greenhouse evaluation were applied using a hand-held sprayer equipped with an 8001E spray tip delivering 300 L/ha diluent volume of water at 210 kPa pressure. Treated foliage was removed 2 weeks after treatment. Shoot regrowth and rhizome dry weight were measured 8 WAT for both foliar and soil applied herbicide evaluations.

Field herbicide evaluation. Two field sites were included for herbicide evaluation. Site 1 was located on a clay "settling pond" on reclaimed phosphate strip-mined land (IMC-Agrico Mining) in central Florida. Waste clays are a bi-product of phosphate mining and are pumped into impoundments (settling ponds). These soils are classified as hydraquents and are approximately 85% montmorillonite, kaolinite, and illite clay, 10% silt, and 5% sand. Site 2, also in central Florida, was located in the Withlacoochee State Forest. The soil was a loamy, siliceous, hyperthermic, Grossarenic Paleudult of approximately 90% sand, 6% silt, and 4% clay (Arredondo-Sparr-Kendrick association). Herbicide applications were made on 26 June and 8 July in 1993 and 1994, respectively, at site 1, and on 21 and 20 October in 1993 and 1994, respectively, at site 2. For soil-applied herbicides, cogongrass foliage was burned one day before treatment, leaving a fine ash or bare soil.

Efficacy was determined by visually estimating shoot regrowth relative to the untreated check at 3, 6 and 12 months after treatment (MAT) and expressed as percent control.

For the field studies, herbicides were applied using a backpack sprayer with a 3.25 m hand-held boom, equipped with 8003 flat fan nozzle tips, delivering 170 L/ha diluent volume at 220 kPa pressure. Plot size was 3.25 by 6.50 m.

Timing of glyphosate application. The influence of glyphosate application timing on efficacy was evaluated by applying glyphosate (0.56, 1.12, 2.24, and 4.48 kg/ha) at 4 dates in 1993 (June, August, October, and December). January was added as a fifth application date in 1994. Periodic visual evaluations of herbicide efficacy were conducted and shoot biomass harvested from a 1 m^2 area in December (18 months after the first treatment date).

All greenhouse and field studies were conducted twice using randomized complete block designs with a minimum of three replications. Analyses of variance (ANOVA) were conducted and means separated by LSD at the 0.05 level of probability. Herbicide I_{50}s were calculated for evaluations under greenhouse conditions using the linear regression equation. No significant interactions ($p>0.05$) existed between years and treatments for the field studies, therefore data for 1993 and 1994 were combined.

Results and Discussion

Greenhouse herbicide methodology. Shoot and rhizome growth was inhibited nearly 100% with all rates of glyphosate applied to 3- and 6-week-old plants. Therefore, I_{50}s could not be calculated (Table 2.1). The I_{50}s for 9-week-old plants were likewise low. The I_{50}s were similar for 12-, 15-, and 18-week-old plants. Rhizome response to glyphosate was more erratic, but I_{50}s were comparable to those for shoot growth observed with 12-week-old plants.

Growth inhibition decreased (ie., higher I_{50}s) as time of evaluation increased (Table 2.2). Five weeks after treatment is an insufficient response time. Shoot regrowth did not occur even at 0.56 kg/ha and the I_{50}s were low for both shoots and rhizomes. The I_{50} for rhizomes remained consistent for 7, 11, and 15 week evaluation periods. At least 7 WAT was needed before evaluating the response of cogongrass to herbicides. Shoots and rhizomes will have had time to regrow, and waiting longer would only decrease the difference between treated and untreated plants. This would occur because the control plant rate of growth will eventually diminish, thus allowing treated plants to achieve similar biomass given enough time.

Greenhouse herbicide evaluation. Of the original 17 herbicides evaluated, fenoxaprop, imazaquin, primisulfuron, quinclorac, sethoxydim, and vernolate were eliminated from further evaluation because of unacceptable efficacy (i.e.

less than 50% inhibition 4 WAT; data not shown). Applied postemergence over-the-top (POE), the lowest I_{50} for shoot growth was achieved with nicosulfuron, followed, in ascending order (decreasing efficacy), by imazameth, imazethapyr, quizalofop, imazapyr, glyhosate, sulfosate, fluazifop (Table 2.3). For rhizomes, nicosulfuron again had the lowest I_{50}, followed, in ascending order, by imazameth, imazethapyr, imazapyr, quizalofop, sulfosate, glyphosate, and fluazifop.

When herbicides were applied to soil after removing foliage, the lowest I_{50} for shoot regrowth was achieved with sulfometuron, followed, in ascending order, by imazameth, imazethapyr, metsulfuron, and imazapyr (Table 2.4). Pendimethalin was applied at 0.56, 1.12, 2.24, and 4.48 kg/ha but no inhibition of cogongrass regrowth was observed even at the highest rate (data not shown), and no I_{50} could be determined. The I_{50} of metsulfuron was reduced 45% when pre-mixed and applied with pendimethalin. The I_{50} of imazameth did not change when applied with pendimethalin.

The I_{50} values obtained from these studies may be misleading. Imazapyr provided nearly complete inhibition of regrowth at all rates, indicating that a true nonlethal dose was not applied. The dry weight harvested from the imazapyr treatments was growth that occurred within the first two days after treatment, at which point growth stopped. Thus, the true I_{50} for imazapyr may actually be lower than

determined in this study.

Correlating data gathered under greenhouse conditions with results obtained from field studies is problematic. Although the relative responsiveness of cogongrass to herbicides can be obtained from greenhouse studies, a true appraisal of herbicide efficacy must be ascertained under field conditions. Determining growth patterns and optimal timing of herbicide application and evaluation are valuable tools for herbicide evaluation in the greenhouse and may be helpful in evaluating relative efficacy differences among herbicies, for identifying interesting phenomena, or for clarifying physiological plant-herbicide interactions.

Field herbicide evaluation. The highest concentrations of imazapyr, glyphosate, and fluazifop inhibited cogongrass shoot growth greater than 50% six months after treatment (MAT) at site 1. By 12 MAT, however, only imazapyr at 2.24 kg/ha provided over 50% control (Table 2.5). Glufosinate caused acute toxicity (complete necrosis within 10 days after application), but regrowth from rhizomes was evident by 2 MAT, and by 6 MAT control was only 43%. Neither imazameth nor nicosulfuron were effective at the rates applied. Glyphosate at the highest rate and imazapyr at all rates provided excellent control 12 MAT at site 2. Fluazifop maintained 50% control up to 6 MAT at site 2, but control declined to near zero by 12 MAT. Nicosulfuron caused early chlorosis and some necrosis at all rates but

provided unacceptable control. Imazameth and glufosinate were added to the study in 1994, and both provided some suppression of cogongrass 9 and 12 MAT. However, these herbicides did not provide long term control at either site at the applied rates.

Soil applied herbicides after burning foliage were ineffective at site 1, with only imazapyr suppressing cogongrass at 1 MAT (data not shown). By 3 MAT, cogongrass was only slightly stunted from imazapyr and control was near zero. At site 2, soil applications of imazapyr provided excellent control at 6 and 9 MAT (99 and 94%, respectively), but by 12 MAT control was only 54% (Table 2.6). Likewise, sulfometuron inhibited growth at early evaluations but control was lost by 12 MAT. Cogongrass was not suppressed by imazethapyr, imazaquin, or metsulfuron at any evaluation date (data not shown).

Timing of glyphosate application. Glyphosate applied in December provided the best control 12 and 16 months (June and October visual evaluation) after the first treatment date (Table 2.7). Similar results were observed based on shoot biomass at one year after the December treatment, but only the highest rate reduced cogongrass growth more (94%) than other rates and treatment dates. Although the September and January treatment dates were only 3 and 1 month prior and subsequent to the December date, respectively, neither treatment reduced growth by half that

of the 4.48 kg/ha rate applied in December.

Herbicides were highly effective under greenhouse conditions when applied within label rates, but only imazapyr, glyphosate, and sulfometuron provided long-term (>6 months) control under field conditions. Imazapyr applied to the soil provided excellent control for up to 9 months at site 2. When the same herbicides were applied to the clay soils of mined land, acceptable control was not achieved. Autumn foliar applications of imazapyr and glyphosate reduced cogongrass growth more than soil-applied herbicides or herbicides applied in the spring or summer. Imazapyr was the most efficacious of any herbicide, reducing cogongrass growth by 89% at 0.56 kg/ha 12 MAT when applied in the fall to cogongrass growing on sandy soil.

Numerous factors may have contributed to greater efficacy at site 2. The stand of cogongrass at site 1 was more dense, with a biomass of 499 g/m^2 compared to 179 g/m^2 of above-ground biomass at site 2. Rhizomes occupied only the top 10 to 15 cm of soil at site 2, while rhizomes at site 1 were consistently found at depths of 80 cm.

The high clay content of the soil at site 1 probably contributed to greater binding and less residual activity of herbicides relative to the sandy soil at site 2. The late application date may have been the overriding factor, as observed in the timing of glyphosate application study. New shoots would be much less likely to emerge after initial

kill due to lower temperatures and drier conditions after the late application date. Tanner et al. (1992) reported fall treatments of glyphosate provided greater cogongrass control than spring or summer treatments.

Frequent rainfall from August through September may have diminished activity of glyphosate when applied during this time period. Enhanced basipetal translocation may have occurred due to a greater translocaton of photosynthate to rhizomes during this time of the year during the December treatment time. Potter et al. (1986), reported that total nonstructural carbohydrate concentration in roots of prickly-pear cactus was lowest on 1 July, and replenishment occurred from early autumn to midwinter. Nonstructural carbohydrate concentation in torpedo-grass increased in the fall (Smith et al., 1993). Finally, rhizomes which remain viable continue respiratory processes and lose carbon. In forage species, severe defoliation followed by a period of stress (such as cold, dry weather common in central Florida from December through March) limits regrowth (Richards, 1993). Nonstructural carbohydrate reserves may be depleted by respiration by the time adequate temperatures and moisture necessary to resume growth occur, thereby reducing regrowth. The poor control observed from the January application may be explained by dead leaves intercepting the herbicide. Cogongrass naturally senesces during this period of the year and may have reduced herbicide efficacy.

Options exist for management of cogongrass with herbicides. Imazapyr was the most effective herbicide available for long-term cogongrass control. Glyphosate was also very effective and both herbicides provided better control when applied in the fall. Herbicides applied to cogongrass foliage were more effective than when applied to soil after removing foliage. Complete control of cogongrass was not achieved with one application of any herbicide, and split or sequential herbicide applications or combining herbicide with tillage or cultural control measures is needed for greater cogongrass control.

Table 2.1. The effects of plant age on glyphosate efficacy based on I_{50}s.

Plant Age	Shoot Regrowth	R^2	Rhizome	R^2
(weeks)	(kg/ha)		(kg/ha)	
3	--	--	--	--
6	--	--	0.38	0.58
9	0.27	0.49	0.54	0.54
12	0.89	0.60	0.82	0.82
15	0.88	0.55	1.19	0.46
18	0.83	0.75	0.95	0.79

Note: I_{50} is the herbicide rate required to inhibit growth 50%.

Table 2.2. The effects of response time on glyphosate efficacy based on I_{50}.

WAT	Shoot Regrowth	R^2	Rhizome	R^2
	(kg/ha)		(kg/ha)	
5	0.13	0.46	0.27	0.54
7	0.28	0.51	0.70	0.69
11	0.63	0.75	0.70	0.63
15	0.53	0.70	0.65	0.72

Note: I_{50} is the herbicide rate required to inhibit growth 50%.

Table 2.3. The effects of postemergence herbicide applications on cogongrass growth.

Herbicide	Shoot Biomass			Rhizome/Root Biomass		
	I_{50}[a]	CL[b]	R^2	I_{50}[a]	CL[b]	R^2
	- - - g/ha - - -			- - - g/ha - - -		
Fluazifop	0.28	0.22 - 0.35	0.66	0.23	0.17 - 0.31	0.59
Glyphosate	0.24	0.15 - 0.33	0.64	0.20	0.00 - 0.30	0.51
Imazameth	0.04	0.03 - 0.05	0.71	0.04	0.02 - 0.05	0.56
Imazapyr	0.15	0.11 - 0.19	0.70	0.10	0.00 - 0.14	0.56
Imazethap	0.05	0.04 - 0.06	0.81	0.03	0.02 - 0.05	0.58
Nicosulfn	0.01	0.00 - 0.05	0.52	0.02	0.00 - 0.04	0.55
Quizalofop	0.11	0.08 - 0.16	0.59	0.13	0.08 - 0.30	0.35
Sulfosate	0.26	0.16 - 0.42	0.47	0.18	0.13 - 0.23	0.68

[a] Herbicide rate required to inhibit growth 50%.
[b] 95% confidence limits.

Table 2.4. The effects of preemergence herbicides on cogongrass growth.

Herbicide	Shoot Biomass			Rhizome/Root Biomass		
	I_{50}[a]	CL[b]	R^2	I_{50}	CL[b]	R^2
	- - - g/ha - - -			- - - g/ha - - -		
Imazameth	0.04	0.03 - 0.05	0.92	0.03	0.02 - 0.05	0.74
Imazapyr	0.20	0.00 - 0.30	0.85	0.18	0.00 - 0.28	0.57
Imazethapyr	0.11	0.09 - 0.13	0.67	0.08	0.05 - 0.12	0.26
Metsulfuron	0.11	0.08 - 0.15	0.53	0.07	0.04 - 0.10	0.77
Sulfometn	0.02	0.01 - 0.02	0.99	0.01	0.00 - 0.02	0.95
Metsulfn/	0.06	0.04 - 0.07	0.75	0.04	0.03 - 0.06	0.55
Pendimethn	0.73	0.47 - 1.19		0.51	0.35 - 0.72	
Imazameth/	0.04	0.03 - 0.05	0.83	0.03	0.02 - 0.04	0.58
Pendimeth	0.52	0.42 - 0.64		0.33	0.19 - 0.79	

[a] Herbicide rate required to inhibit growth 50%.
[b] 95% confidence limits.

Table 2.5. Control of cogongrass under field conditions with foliar applied herbicides at two sites in Central Florida.[1]

		Site 1		Site 2	
Herbicide	Rate	6 MAT[2]	12 MAT	6 MAT	12 MAT
	kg/ha	----------		%[4] ----------	
Fluazifop	0.56	75	48	50	5
	0.28	48	15	21	0
	0.14	30	20	44	0
Glufosinate[3]	2.24	43	30	80	65
	1.12	33	10	33	33
	0.56	25	5	10	23
Glyphosate	4.48	53	25	100	86
	2.24	53	13	99	66
	1.12	45	18	96	46
Imazameth[3]	0.12	10	20	60	45
	0.06	3	5	30	26
	0.03	15	5	8	5
Imazapyr	2.24	83	58	90	96
	1.12	83	23	84	88
	0.56	65	15	88	89
Nicosulfuron	0.07	15	20	38	25
	0.03	20	15	29	0
	0.015	13	23	29	0
LSD (0.05)		23	10	12	6

[1] Data pooled over two years.
[2] Months after treatment.
[3] Applied in 1994 only.
[4] Based on visually estimated shoot growth.

Table 2.6. Percent control of cogongrass under field conditions from soil-applied herbicides at site 2.[1]

Herbicide	Rate	6 MAT[2]	9 MAT	12 MAT
	-- kg/ha --	-------- % control[3] --------		
Imazapyr	2.24	99	94	54
	1.12	73	81	53
	0.56	60	50	26
Sulfometuron	0.12	89	60	26
	0.06	71	39	13
	0.03	60	41	11
LSD (0.05)		20	22	15

[1] Data pooled over years.
[2] Months after treatment.
[3] Based on visually estimated shoot regrowth.

Table 2.7. Percent control of cogongrass with glyphosate applied at 5 dates at 12, 16, and 18 months after June treatment date.[1]

Treatment Date	Rate	Control 12[2]	16[2]	18[3]
	kg/ha	- - - - - - - - - - % - - - - - - - - - -		
June	0.00	0	0	0
	0.56	14	3	20
	1.12	29	8	8
	2.24	21	10	0
	4.48	45	40	30
August	0.00	0	0	0
	0.56	10	4	18
	1.12	10	5	21
	2.24	26	14	27
	4.48	38	20	47
October	0.00	0	0	0
	0.56	11	5	24
	1.12	15	10	14
	2.24	41	16	27
	4.48	40	10	34
December	0.00	0	0	0
	0.56	35	14	0
	1.12	41	23	4
	2.24	66	43	44
	4.48	85	81	94
January	0.00	0	0	0
	0.56	5	3	0
	1.12	30	13	10
	2.24	50	15	45
	4.48	40	25	37
LSD ($p<0.05$)		21	18	12

[1] Data pooled over years.
[2] % control based on visual evaluations.
[3] % control based on dry weight of shoot biomass (mean of untreated control was 532 g/m^2).

CHAPTER 3

APICAL DOMINANCE AND AXILLARY BUD ACTIVITY IN COGONGRASS

Introduction

Cogongrass (*Imperata cylindrica* (L.) Beauv.) is a serious pest throughout tropical and subtropical regions of the world and ranked as the seventh most troublesome weed worldwide (Holm et al., 1977). Cogongrass is a perennial, rhizomatous, C_4 grass which also reproduces from seed. Cogongrass was introduced to the United States by accident in packing crates from Japan, and was also evaluated in the United States as a potential forage in Alabama, Florida, and Mississippi (Dickens, 1977; Tabor, 1952). It is now a problem in the southeastern United States and gulf states region (Bryson, 1993). The persistent, large, rhizome mass with numerous dormant buds allows cogongrass to survive chemical and mechanical control and repeat treatments are needed to eliminate or reduce cogongrass swards. Determining the mechanism of bud dormancy and how to manipulate rhizome growth could lead to the development of more effective control measures.

Existing information dealing with physiological control of rhizome bud development in cogongrass is inconsistent.

Peng (1984) found no sprouting from rhizome segments. Hubbard (1944) found that even small fragments generated new plants. Wilcut et al. (1988) reported that axillary buds were not found on rhizome nodes except at the apex, thus precluding shoot production from most of the rhizome system. Ayeni (1985) observed that the development of buds and roots or rhizomes starts long after rhizome formation, and that buds on only the convex side of the apical curvature of mature rhizomes form new rhizomes. Ayeni and Duke (1985) reported that young rhizomes were not capable of producing aerial shoots, and that regenerative capacity increased with advancing age. The authors also hypothesized that a certain level of carbohydrates, nutrients, and essential enzymes must be present before rhizomes will regenerate.

Extensive research has been conducted on quackgrass (*Agropyron repens* (L.)), a rhizomatous, perennial grass of temperate climates. Smith and Rogan (1979) reported that allocation of assimilates between old and young shoots and rhizomes maintains a system of reciprocal dominance in quackgrass, first described as correlative inhibition by Goebel (1900). McIntyre and Hsiao (1982) caused a release of bud dormancy in quackgrass rhizomes by increasing the nitrogen supply to the parent shoot or by raising the humidity around the rhizome. Hunter et al. (1993) reported that increasing the nitrogen supply from 10.5 to 210 mg L^{-1} reduced glyphosate-induced inhibition of bud growth in

quackgrass. The authors postulated that increased growth with the greater nitrogen supply diluted the glyphosate to less toxic levels, or that disruption of amino acid metabolism by glyphosate was limited with the greater nitrogen supply.

Auxin (indole-3-acetic acid (IAA)), may also play a role in bud dormancy. Cline (1994) summarized the hypothesis of auxin-induced inhibition: apically produced auxin moves basipetally down a shoot into lateral buds and directly inhibits their outgrowth. The author also stated that research on auxin is difficult due to the uncertainty of application methods and because concentrations within the plant are difficult to ascertain. Chancellor and Leakey (1972) reported that IAA caused a slight reduction in shoot lengths and in the number of shoots in quackgrass. Other growth regulators such as naptalam, which has been shown to block polar transport of auxin (Sussman and Goldsmith, 1981), may help clarify controlling factors of bud dormancy. Extensive research has been conducted with growth regulators on dicots, but minimal work has been reported for grasses. This dearth of information may be due to the complex system of buds and shoots and, relative to dicots, cryptic meristematic regions (Smith and Rogan, 1979).

Because of the apparent contradictions and lack of information concerning growth and development of axillary buds in cogongrass, experiments were undertaken to evaluate

factors influencing bud activity and development in cogongrass rhizomes.

Materials and Methods

The influence of the apex on bud activity was evaluated by harvesting and planting rhizome segments of 2, 4, 8, and 16 nodes in flats, with and without the apex. The segments were covered with 2 cm of potting soil and grown in the greenhouse. Three weeks after planting, the activity of buds was evaluated by counting vertical shoots produced from the rhizome bud.

An auxin add-back study was conducted to evaluate the potential of indole-3-acetic acid (IAA) as the means of inhibition caused by the presence of the apex. Apical rhizome sections were harvested from a mature stand of cogongrass, the cataphylls removed, and rhizomes of similar girth and internode length selected for treatment. Indole-3-acetic acid (IAA) was mixed with 10 ml of dimethyl sulfoxide (DMSO) and water to form a true solution, and mixed with 4% agar to obtain IAA concentrations of 62.5, 125, 250, 500, and 1000 $mg\text{-}L^{-1}$ in 1% DMSO. The control consisted of LMSO, water, and agar. Rhizome segments which did not receive any treatment were also included as controls. The respective treatments were poured into plastic scintillation vials. A hole had been drilled 0.5 cm from the bottom in the side of each vial and the hole sealed with tape. When the agar had solidified, the apex of the

selected rhizomes was excised, and the freshly cut apical rhizome end inserted into the hole in the side of the scintillation vial. The rhizomes with their respective IAA concentrations in agar were placed on trays, and the rhizomes covered with moist vermiculate. The entire tray was covered with aluminum foil and placed in a dark growth chamber at 30 C. Each day, the foil was removed from the vials and the respective IAA solutions added to the agar as needed to replace any evaporative loss. At 8 days after initial treatments, only de-ionized water was added to all vials, essentially diluting the IAA in the vials, but preventing the agar and rhizome tips from dessication. Bud activity, measured as vertical shoot development from buds, was evaluated at 8 and 16 days after the treatments had been started.

The potential to break apical dominance with growth regulating chemicals was also evaluated. Apical rhizome sections were harvested from a mature stand of cogongrass and treated by soaking the apex in 1000 mg/L tri-iodo benzoic acid (TIBA), 100 mg/L metsulfuron, or 1000 mg/L naptalam. The apex was left intact, and the control consisted of soaking the apex in de-ionized water. The rhizomes were soaked for either 5 or 15 minutes in the respective solutions and transferred to glass tubes with a glass-wool/water growing medium. The tubes were sealed and rhizomes evaluated for shoot production 14 days after

treatment.

The role of nitrogen in bud activity was evaluated by harvesting rhizomes as previously described and removing the apex from half of the segments. All segments were planted in 10 L tubs of vermiculite/perlite (1:1 ratio) growing medium. These tubs were placed in the greenhouse under the following conditions: 35 C day/24 C nights; 16 h day/8 h night. The nitrogen treatments consisted of 1, 10, and 100 $mg\text{-}L^{-1}$ nitrogen supplied in a modified Hoagland's solution (Hoagland and Arnon, 1950) every third day, and subirrigated with tap water on other days as needed. The rhizomes were evaluated for shoot and rhizome number 6 weeks after sowing in the tubs.

All studies were conducted as randomized complete block designs and conducted twice with 4 replications. Interactions between duplicate studies and treatments did not exist ($p>0.05$) and data were therefore pooled. Data were subjected to analysis of variance and means separated using Fisher's protected least significant difference.

Results and Discussion

Shoot production increased as rhizome length (ie., node number) increased, and the difference between apical and nonapical sections became greater as rhizome length increased (Table 3.1). Shoot number was 17, 23, and 31% greater with the apex removed at each ascending node number, respectively, compared to rhizomes with the apex intact.

Shoot development from rhizomes with the apex removed was random along the length of the rhizome. Shoot development from rhizomes with the apex intact was confined to a 2 to 4 cm portion of the rhizome apex.

All concentrations of IAA suppressed shoot formation relative to the control (Table 3.2). Untreated rhizomes with the apex present consistently produced only one apical shoot (data not shown). Rhizomes treated with 1000 mg-L^{-1} IAA produced either one or zero shoots, similar to untreated rhizomes with the apex intact. All rhizomes remained firm, white, and produced roots at most nodes, thus death of rhizomes or rhizome apices was not a concern. Rhizomes treated with IAA concentrations of 62.5 to 500 mg-L^{-1} responded similarly, producing from 37 to 48% fewer shoots than the control. When these rhizomes were allowed to grow for another 8 days without additional IAA added to the agar, bud activity increased in nearly all rhizomes, but to a relatively greater degree in those rhizomes most suppressed by initial high IAA solutions. By inserting the apical end into the agar, more normal basipetal translocation may be possible. However, the argument of Cline (1994) that the actual concentration of IAA within the rhizome is unknown remains valid. Further, Hillman et al. (1977) reported IAA levels increased in lateral buds of *Phaseolus* after excising the shoot apex, and stated that application experiments have limited value for determining the physiology of apical dominance.

Tri-iodobenzoic acid and metsulfuron did not increase bud activity, and the 15 minute metsulfuron treatment killed the rhizomes (Figure 3.1). Naptalam, a chemical which inhibits polar auxin translocation, activated buds with both a 5 and 15 minute treatment. The 15 minute treatment resulted in bud activation similar to the control in which the apex was excised. Naptalam applications to foliage did not change plant growth or morphology when evaluated at numerous concentrations, at various growth stages, and with various surfactants (data not shown). Naptalam probably does not translocate from leaves and direct application to rhizomes was needed to illicit a response.

The highest nitrogen concentration (100 mg/L) caused an increase in both shoot and rhizome numbers regardless of presence or absence of the apex. No differences from apex treatment were observed at the 100 mg-L^{-1} nitrogen concentration (Table 3.3). The presence of the apex was inhibitory to shoot and rhizome production from apical rhizome segments at 1.0 and 10.0 mg-L^{-1} nitrogen. When the apex was removed, shoot and rhizome production increased by 72 and 58%, respectively, at 1 mg-L^{-1} nitrogen, and 51 and 37% at 10 mg-L^{-1} nitrogen, respectively, relative to those rhizomes where the apex remained intact.

Based on these studies, apical dominance in cogongrass is affected by the presence or absence of the apex, and IAA is a contributing factor to bud dormancy. The role of

nitrogen is also important for growth and development of axillary buds, and in these studies activated bud development at high concentrations and when luxuriant shoot growth occurred. Development of axillary buds into shoots or rhizomes as a result of high nitrogen availability seemed to be a result of increased growth rather than an activation of axillary meristems.

Inhibition of bud growth is an important survival mechanism in perennial species, providing a means of energy conservation and regenerative capacity. High nitrogen availability seemingly disrupts this survival mechanism in cogongrass. However, upon closer view, high nitrogen allows abundant growth, greater dry matter production and a greater number of rhizomes which more than replace the formerly dormant buds on the parent rhizome. Thus, the survival potential is maintained or increased. The ability of cogongrass to effectively utilize abundant nitrogen may give cogongrass a competitive advantage under many diverse conditions. In poor soils, buds remain dormant and survival is emphasized. Conversely, when nitrogen is readily available cogongrass grows prolifically.

Management implications based on this information are uncertain. As Hunter et al. (1993) observed in quackgrass, a high nitrogen availability increased glyphosate translocation in rhizomes, but also reduced herbicide efficacy due possibly to a dilution effect on the herbicide

by greater dry matter production. Breaking apical dominance may change the shoot to rhizome ratio and provide greater avenues for herbicide translocation into the rhizomes. However, increased shoot growth was present at 2 weeks after mechanically breaking apical dominance in elephantgrass (Sollenberger et al.,1990), but by 6 weeks after treatment shoot growth from stems with the apex removed was less than in shoots with the apex intact.

Table 3.1. The influence of node number and apex on shoot production from cogongrass rhizomes.

Apex Treatment	Node number		
	4	8	16
Apex intact	1.9	3.4	5.9
Apex removed	2.3	4.4	8.6
LSD (0.05) = 0.7			

Table 3.2. The influence of indole-3-acetic acid (IAA) concentration and days of treatment on bud activity in rhizome segments with apex removed.

Days After Treatment	IAA concentration (mg/L)					
	0.0	62.5	125	250	500	1000
	- - - - - - - number of shoots - - - - - - -					
8	3.38 a[2]	2.13 b	2.13 b	1.75 b	2.0 b	0.75 c
16	3.50 a	2.63 b	2.13 b	2.13 b	2.25 b	1.38 c

Note: Means within a row followed by different letters are significantly different at the 0.05 level of probability according to Duncans's Multiple Range Test.
[2] Untreated rhizomes with apex present produced 1 apical shoot.

Table 3.3. Influence of nitrogen and apex on cogongrass shoot and rhizome growth.

	Nitrogen Concentration (mg/L)					
Apex Treatment	1.0		10.0		100.0	
	shoots	rhizomes	shoots	rhizomes	shoots	rhizomes
	- - - - - - - - - - - - no. - - - - - - - - - - - -					
apex intact	2.69a[1]	1.75a	5.73a	4.09a	9.80a	8.57a
apex removed	7.25b	2.56b	9.00b	9.50b	11.81a	9.13a

[1] Means within a column followed by different letters are significantly different from each other at the 0.05 level according to Fischer's test for significance.

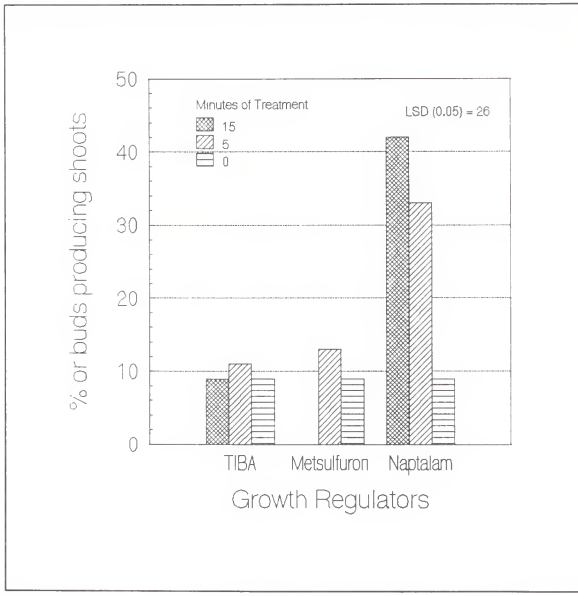

Figure 3.1. The influence of plant growth regulators on apical dominance in cogongrass rhizomes.

CHAPTER 4

THE RESPONSE OF COGONGRASS TO CHEMICAL CONTROL FOLLOWED BY REVEGETATION WITH DESIRABLE SPECIES

Introduction

Imperata cylindrica (L.) Beauv. is an invasive, noxious, rhizomatous grass that grows in natural and disturbed sub-tropical and tropical ecosystems. Chemical control has been reported using fluazifop (Akobundo, 1993), glyphosate and imazapyr (Akobundo, 1993; Boonsritat et al., 1985; Lee, 1985; Mabb and Price, 1986; Townson and Butler, 1990). Combinations of chemical and mechanical control have also been reported to be effective (Willard et al., 1996). However, repeat applications are necessary for complete control (ie. long-term control). The bare soil, which results when chemical control is successful, may lead to soil erosion and create a potential for reinfestation. Thus, simply suppressing cogongrass with a herbicide will not prevent reinfestation and may have undesirable consequences.

Little regard has been given to revegetation of infested areas, and the long-term control of cogongrass in range-land and forest situations can only be achieved by changing the vegetation from a dominant monoculture of

cogongrass to a competitive, diversified plant community. Replacing cogongrass would require integrating chemical or biological suppression with cultural (competition) suppression. If managed properly, plant species used to suppress cogongrass could could eventually replace it. Plants used as cover crops, smother crops, or green manure have the potential to increase soil nitrogen, improve soil properties, increase biological activity in the soil, and control weeds (Akobundo, 1992; Buckles, 1995; Sanchez and Benites, 1987). For example, *Mucuna* spp. is a vigorous, climbing legume which has been used for centuries as a cover crop and green manure in the tropics (Buckles, 1995).

Akobundo (1992), in Ibadan, Nigeria, reported that *Mucuna pruriens* (L.) var. *utilis* (Wight) Burck, *Pueraria phaseoloides* (Roxb.) Benth., *Centrosema pubescens* Benth, and *Psophocarpus palustris* Desv. used as live mulches prevented erosion, added organic matter to the soil, reduced the need for nitrogen fertilizer, suppressed weed growth and depleted the soil weed-seed bank. In Yurimaguas, Peru, *Pueraria phaseoloides* was used as a fallow crop to preserve agroecosystem diversity, limit weed pressure, and sustain production in humid tropic oxisols and ultisols (Sanchez and Benites, 1987).

In the southern United States, cogongrass has invaded rangelands, roadsides, forests, and reclaimed mining sites. Little attention has been given to maintaining these areas

free of cogongrass once initial control measures have been implemented. Therefore, the objective of this study was to determine if the integration of several control methodologies could provide sustained long-term control of cogongrass.

Materials and Methods

Studies were conducted in central Florida from 1993 to 1995 on reclaimed phosphate strip-mined land. In 1993 the study was located on a reclaimed phosphate mining site on which the original top soil had been returned (IMC-Agrico Mining). Before mining, the soil was a sandy, silacious haplaquad (97.5% sand, 2.2% silt, 0.3% clay) (USDA/SCS, 1990). The area was a bahiagrass/hairy indigo (*Paspalum notatum/Indigofera hirsuta* (Harv.)) pasture which had become severely infested with cogongrass. In 1994 the study was located on a reclaimed clay "settling pond." Waste clays are a by-product of phosphate mining and are pumped into impoundments (settling ponds). These soils are classified as hydraquents and are approximately 85% montmorillonite, kaolinite, and illite clay, 10% silt and 5% sand. The soil was poorly drained and some areas of the study site were subjected to seasonal flooding.

The studies were arranged in a 2 by 3 by 5 factorial, split-split plot design with four replications on 6 by 6 m plots. Main plots consisted of fertilizer [450 kg/ha of N(10)-P(10)-K(10)] or no fertilizer, sub-plot treatments

were glyphosate (as Roundup, 360 g ai/l, Monsanto Agricultural Co.), imazapyr (as Arsenal, 240 g ai/l, American Cyanamid Co.), or an untreated control, and the sub-subplots were revegetation species (Hairy indigo (*Indigofera hirsuta* (L.)), perennial ryegrass (*Lolium perenne* (L.)), bahiagrass (*Paspalum notatum* Fluegge), switchgrass/partridge pea (*Panicum virgatum* (L.))/*Chamaecrista fasciculata* (Michx.) Greene, and an unseeded control). In 1994, bermudagrass (*Cynodon dactylon* (L.) Pers.) replaced *L. perenne*.

In 1993, herbicides (2240 and 840 g a.i./ha of glyphosate and imazapyr, respectively) were applied to cogongrass on 25 July. On 17 September, the area was mowed, main plots fertilized, the entire area disced, and desirable species seeded to designated sub-subplots. In 1994, the area was burned in May, herbicides applied (1993 rates) to regrowth on 01 June, and subsequent fertilizing and seeding completed on 29 June 1994. Herbicides were applied using a CO_2-pressurized back-pack sprayer and hand-held boom equipped with 8003 flat fan nozzle tips delivering 280 l/ha at 210 kPa pressure. Above-ground biomass was collected from a 1 m^2 area within each plot 12 months after the final treatment (MAT), sorted into seeded species and cogongrass, dried and weighed. Data were subjected to analysis of variance to test for main effects and interactions. Means were calculated and are presented with standard errors.

Data from each year are presented separately.

Results and Discussion

1993 season. In 1993 *Indigofera hirsuta* was the only species to establish with uniform coverage and data are not shown for the other species. A species by herbicide interaction existed for biomass of seeded species in 1993 at the $p<0.01$ level (Table 4.1). *Indigofera hirsuta* was the most competitive of all species evaluated in 1993 regardless of herbicide used. *Indigofera hirsuta* in combination with imazapyr produced 66 and 120% more above-ground biomass than in combination with glyphosate or an untreated control, respectively. *Indigofera hirsuta* and imazapyr provided 63, 100, and 53% control, respectively, of cogongrass relative to the untreated/unseeded control. The interaction occurred because imazapyr was the most effective herbicide for cogongrass control and *I. hirsuta* is relatively tolerant of imazapyr. Thus, the greatest *I. hirsuta* growth, and, consequently, the least cogongrass growth, occurred with the imazapyr/*I. hirsuta* combination. *Indigofera hirsuta* is an annual legume native to tropical Africa and Asia, growing erect, which is adapted to well-drained, somewhat dry, sandy soils. It is an excellent green manure and provides high quality forage when immature (Baltensperger et al., 1985.). A mixture of *C. fasciculata* and *P. virgatum* after imazapyr treatment provided 86% control of cogongrass at 12 MAT (data

not shown). Although no *C. fasciculata* or *P. virgatum* biomass was measured at 12 MAT, both species had emerged and grew in the year of seeding. Any control was likely due to this growth and residual activity of imazapyr. These species are native in Florida. *Chamaecrista fasciculata* is found in open woodlands, prairies, and occasionally along streambeds on poorly-drained soils, and *P. virgatum* is found anywhere from pond margins and wet prairies to *Quercus* ridges (Hall, 1978). As natives, they are suitable for reclamation of ecosystems, but uniform germination and seedling establishment are difficult due to dormancy mechanisms and non-viable seed. Combinations of imazapyr and *P. notatum*, a perennial, tropical forage grass, or *L. perenne*, a perennial, cool-season grass, provided less control than imazapyr alone. *Lolium perenne* may be useful as an initial revegetation species for the cool season of the sub-tropics, but will not survive extreme temperatures of summer. *P. notatum* is slow to establish and may be limited in use for revegetation where cogongrass remains competitive.

Regardless of species seeded, imazapyr provided superior control to glyphosate (Tables 4.1 and 4.2). Although biomass data was collected only up to 12 MAT, plots treated with imazapyr and seeded with *I. hirsuta* remained free of cogongrass 24 MAT, apart from some encroachment from adjacent plots. Poor establishment of the seeded species

was attributed to two factors. One, most grew slowly and were not able to overcome cogongrass even after suppression with glyphosate. Two, imazapyr provided longer term suppression of cogongrass, but soil residual activity prevented growth of all but *I. hirsuta*.

1994 Season. A species by herbicide interaction ($p<0.1$) existed for cogongrass biomass in 1994. The greatest control (55%) 12 MAT of cogongrass was achieved with a combination of imazapyr and an *P. notatum* (data not shown), followed by imazapyr and the unseeded check (40% control) (Table 4.2). *Cynodon dactylon* was the only species established in any plots at 12 MAT, but control achieved with it and imazapyr was only 13%. Once again, an interaction occurred because *C. dactylon* is more tolerant of glyphosate than imazapyr and grew well, adding to long term cogongrass control. Because persistence of the seeded species was poor or nonexistent, suppression of cogongrass in 1994 may be attributed more to the herbicide. However, most seeded species grew well during the first 3 months after seeding and may have hindered re-establishment of *I. cylindrica* in the early stages.

Combinations of glyphosate and revegetation species were not significantly different from the untreated control. Cogongrass, which grew vigorously in 1993 on well-drained sand, grew well and formed a canopy in some areas in the year of seeding in 1994, but did not re-establish the

following season. By 12 MAT only a few *I. hirsuta* plants remained. *C. dactylon*, an unimproved forage species, likewise started well from seed but by 12 MAT only plots on

Table 4.1. Above-ground biomass of cogongrass and *Indigofera hirsuta* as influenced by herbicide in 1993 (12 months after seeding).

	Seeded with *I. hirsuta*	Unseeded
	Biomass of Cogongrass	
	- - - - - - - g/m^2 - - - - - - -	
Glyphosate	66 ± 27[a]	108 ± 34
Imazapyr	0 ± 0	77 ± 28
Untreated	85 ± 32	179 ± 37
	Biomass of *Indigofera hirsuta*	
	- - - - - - - g/m^2 - - - - - - -	
Glyphosate	395 ± 94	-
Imazapyr	654 ± 62	-
Untreated	297 ± 80	-

[a] Means followed by standard errors.

Table 4.2. Above-ground biomass of cogongrass and *Cynodon dactylon* as influenced by herbicide in 1994 (12 months after treatment).

	Seeded with *C.dactylon*	Unseeded
	Biomass of Cogongrass	
	- - - - - - - g/m^2 - - - - - - -	
Glyphosate	322 ± 59[a]	370 ± 46
Imazapyr	272 ± 83	186 ± 55
Untreated	349 ± 53	312 ± 43
	Biomass of *Cynodon dactylon*	
	- - - - - - - g/m^2 - - - - - - -	
Glyphosate	30 ± 30	-
Imazapyr	46 ± 31	-
Untreated	37 ± 37	-

[a] Means followed by standard errors.

higher, more thoroughly-drained ground contained a good stand. As a result, although growth of *C. dactylon* cover was impressive and cogongrass absent in some areas, the control was inconsistent.

Control provided by both herbicides and all herbicide/species combinations was poor in 1994 (Table 4.2). Most species emerged and developed in the summer of seeding but died-back or did not re-establish the following year. Numerous factors may have contributed to poor control of cogongrass and limited growth of revegetation species. The stand of cogongrass on the 1994 site was more dense, with a biomass of 499 g/m^2 compared to 179 g/m^2 of above-ground biomass in the 1993 untreated checks. Rhizomes developed only in the top 10 to 15 cm of soil at the 1993 site. Rhizomes on the clay settling pond (1994 site) were consistently found at depths of 80 cm. Finally, the high clay content of the soil in 1994 probably contributed to greater binding and less residual activity of imazapyr, relative to the sandy soil of 1993. The imidazolinone family of herbicides, of which imazapyr is a member, become somewhat less biologically available as clay content increases (Mangels, 1991).

Revegetation with desirable species after chemical suppression of cogongrass is necessary for sustained, long-term control. This study emphasized the importance of choosing plant species suitably adapted for specific

situations, and with adequate tolerance to the herbicides commonly used for cogongrass management. Imazapyr, while providing greater control of cogongrass than glyphosate, is generally nonselective and has soil residual activity. Glyphosate has no residual activity and could offer flexibility in timing and species selection for revegetion. *I. hirsuta* performed well on a well-drained, sandy soil but grew poorly on a heavy clay soil. Only *I. hirsuta* in 1993 became established, and in 1994 no desirable plant species grew well. Characteristics of species to be considered for future revegetation of clay settling ponds include tolerance of poor drainage, and the ability to establish quickly due to the vigor of cogongrass on clay. Effective, sustained suppression of cogongrass is possible as demonstrated in 1993 with imazapyr and *I. hirsuta*.

CHAPTER 5

INFLUENCE OF LIGHT INTENSITY ON GLYPHOSATE AND IMAZAPYR EFFICACY IN COGONGRASS

Introduction

Cogongrass (*Imperata cylindrica* (L.) Beauv.) is a tropical, C-4 photosynthetic, rhizomatous grass native to southeast Asia (Holm et al., 1977). Glyphosate and imazapyr are proven effective herbicides for cogongrass control. However, chemical control of cogongrass is generally inadequate, requiring repeat applications over 2 or more years to inhibit growth from the extensive rhizome system (Willard et al., 1996). Means of increasing herbicide efficacy in cogongrass and other perennial species may allow reduced application rates, less herbicide in the environment, fewer applications, and greater or more consistent control.

Both glyphosate and imazapyr are readily absorbed and translocated throughout the plant. However, the two herbicides have different mechanisms-of-action. Imazapyr is in the imidazolinone herbicide family and works by binding to the acetolactate synthase enzyme, thereby preventing synthesis of the branched-chain amino acids leucine, isoleucine, and valine (Shaner and O'Connor, 1991).

Imazapyr had little or no effect on respiration, photosynthesis, or lipid or protein synthesis. Imazapyr does suppress DNA synthesis, and the imidazolinones in general increase the levels of free amino acids. Neutral sugar levels in corn leaves also increased in corn plants with 24 h of treatment, likely due to continuation of photosynthesis, while transport of photosynthate out of leaves was inhibited. Applied to cogongrass, imazapyr inhibited leaf elongation within one day of treatment and maximum translocation occurred within 4 days (Shaner, 1988).

Glyphosate, a substituted amino acid, inhibits activity of 5-enolpyruvyl shikimic acid-3-phosphate synthase, thereby preventing synthesis of the aromatic amino acids (Duke, 1985). Glyphosate has other direct or indirect effects on plants. Glyphosate reduced variable fluorescence under light conditions within 4 hours, but not until 44 hours after an initial 24 h dark period followed by alternating 8 h light/8 h dark periods (Madsen et al., 1995). Carotenoid pigment and chlorophyll a and b content of clover and lucerne were reduced 24 h after treatment with 0.15, 1.5, and 15 mM glyphosate concentrations. Photosystem I and II electron transport was affected at 7 days after treatment at all concentrations (Munoz-Rueda et al., 1986). A 17 mM concentration of glyphosate immediately reduced ribulose bisphosphate levels in sugar beet leaves, and phosphoglyceric acid levels were reduced 2 h after

treatment. The rate of photosynthesis followed RuBP decline (Servaites et al., 1987). Shieh et al. (1991) reported that net carbon exchange (NCE) decreased within 1 h after glyphosate application. Geiger and Bestman (1990) reported that glyphosate limits its own phloem transport by limiting CO_2 fixation by processes discussed here and by inhibiting starch synthesis and changing normal carbon allocation. Moosavi-nia and Dore (1979) reported that glyphosate was more efficacious on cogongrass at reduced light intensities, and attributed this to morphological changes of the leaf.

Extensive herbicide translocation is essential for effective control of perennial plants. Environmental conditions which increase self-limitation of herbicide translocation may reduce efficacy of these herbicides. The objective of the experiments included herein was to determine if high light levels decrease efficacy of the phloem-mobile herbicides imazapyr and glyphosate. We hypothesize that glyphosate, which indirectly inhibits photosynthesis, will be more self-inhibitory to translocation than imazapyr, which has a single mechanism that does not interfere with photosynthesis.

Materials and Methods

Light compensation point. Preliminary experiments were conducted to determine the light compensation point (LCP) of cogongrass, needed for subsequent evaluation of herbicide efficacy at different light levels. The LCP is that light

level at which carbon fixed by photosynthesis is equal to carbon lost from respiration. The LCP of greenhouse grown plants of 2, 5, and 15 weeks of age was measured with the LiCor 6200 gas-exchange system. A fully extended leaf of each plant was placed in the chamber and light level varied until carbon flux into and out of the chamber was static. A minimum of 4 replications was used for each age plant and the experiment duplicated. No differences existed between plant ages, replicates, or studies, and all data were pooled for LCP determination. Based on determination of the LCP with the LiCor system, growth of cogongrass at various light levels was determined. Cogongrass plants were grown from 1-node rhizome segments for 3 weeks at ambient light in the greenhouse. Respective plants were then grown under 4 light intensities of 15, 45, 750, and 1500 umol/m^2/s^1 photosynthetic photon flux density (ppfd) for another 12 weeks. Plants were harvested at 3 week intervals and total dry weight was recorded.

Plant fluorometry. Chlorophyll *a* fluorescence as influenced by diuron (2 kg/ha), glyphosate (2 kg/ha), and imazapyr (1 kg/ha) was measured using a Model SF-20 plant productivity fluorometer (Richard Brancker Research Ltd., Ottawa, Canada) on randomly selected leaves of 6-week-old cogongrass plants. A 50 s time was used to establish steady-state fluorescence, an excitation wavelength of 670 nm was used, and fluorescence was measured at 710 nm and

above. The parameters of the fluorescence induction curve, initial (I), peak (P), and terminal (T) fluorescence were recorded. The peak-to-terminal fluorescence ratio was expressed using the following formula:

$$(P-I)/(T-I)$$

Measurements were taken at 30 minutes, 1, 2, 4, 8, 12, 24, and 48 h after treatment.

Herbicide efficacy. The affect of light intensity on herbicide efficacy was evaluated by applying glyphosate (0.08, 0.17, 0.34, 0.68 kg/ha) and imazapyr (0.008, 0.017, 0.034, 0.068 kg/ha) to 8 week-old cogongrass plants grown from 1-node rhizome segments in the greenhouse. Plants were placed in light treatments of 15, 45, 750, and 1500 $umol/m^2/s^1$ 24 h before and 72 h after herbicide application. Ambient light was approximately 1500 $umol-m^{-2}-s^{-1}$ ppfd. Treated shoots were removed one week after herbicide application, and shoot regrowth was measured 8 weeks after treatment.

Herbicides were applied in 175 L/ha diluent volume with a hand-held CO_2 sprayer equipped with an 8001E nozzle tip at a pressure of 210 kPa pressure. DyneAmic, a non-ionic surfactant, was added to each solution at 0.25% v/v.

Data were subjected to analysis of variance and means separated using Fisher's test for least significant difference for fluorescence studies. Regression analysis was used to obtain I_{50} values for glyphosate and imazapyr

efficacy at each light intensity.

Herbicide absorption and translocation. Cogongrass plants were grown from single-node rhizome segments which had been collected from a single stand in Gainesville, FL. These segments were sprouted in trays, replanted in potting soil in 750 cm^3 square pots, and grown at ambient light and day length from 16 December 1995 to 31 January 1996 for the first experiment, and from 13 January to 24 February 1996 for the duplicate experiment. The plants were subirrigated daily. The greenhouse was maintained at approximately 35/25 C day/night temperature, and mid-day ambient light intensity ranged from 1400 to 1600 $umol/m^2/s^1$ at canopy level. Sixteen hours before herbicide applications, plants were moved to respective light treatments of 15, 120, 600, and 1500 $umol/m^2/s^1$.

Plants were oversprayed with nonradio-labelled glyphosate (2.24 kg/ha) or imazapyr (1.12 kg/ha) at sunrise on the day of treatment. The herbicides were delivered with a hand-held micro-applicator equipped with an 8001E spray tip, CO_2-pressurized at 210 kPa, delivering a diluent volume of 300L/ha.

Glyphosate, methyl-labelled with ^{14}C (specific activity of 200 uCi/ml) in an aqueous solution, was prepared for application by mixing 0.045 ml labelled material with 0.045 ml of commercial glyphosate, 0.0025 ml DyneAmic surfactant, and 0.44 ml deionized water for a total activity of 40,000

dpm/ul solution. Imazapyr, ^{14}C-labelled on the imidazole group (specific activity of 212 uCi/ml) in an isopropyl alcohol aqueous solution, was prepared for application by mixing 0.042 ml labelled naterial with 0.0125 ml commercial imazapyr, 0.0025 ml DyneAmic surfactant, and 0.443 ml deionized water, for a total activity of 40,000 dpm/ul solution. When the non-labelled herbicide had dried, each plant received a total of 10 ul of either labelled glyphoate or labelled imazapyr in 5 droplets. The droplets were placed on the second-to-last fully-expanded leaf starting approximately 4 cm from the leaf base. The length of the treated area was 5 cm and was marked with a felt-tip pen. The plants remained in the respective light treatments for 4 days.

Plants were harvested 4 d after tratment. The treated leaf was removed and rinsed for 20 s in 10 ml of a glyphosate/surfactant solution for glyphosate treated plants imazapyr/surfactant solution for the imazapyr-treated plants. Potting soil was lightly rinsed from roots and rhizomes, and whole plants and the treated leaf placed between sheets of newspaper and hardware cloth. The plants were placed in a freezer (-10 C) for 24 h followed by freeze-drying for 36 h. Plants were separated into primary shoots, secondary shoots, roots/rhizome, and the treated leaf. The samples were weighed, ground, and a 25 mg subsample, or the entire sample if the plant part weighed

less than 25 mg, was oxidized and the absorbed $^{14}CO_2$ collected and counted using liquid scintillation techniques. A 1 ml aliquot of the leaf rinse was added to 15 ml of scintillation cocktail and also counted. Based on previous metabolism studies of glyphosate (Sandberg et al., 1980) and imazapyr (Mallipudi et al., 1986), all ^{14}C recovered was assumed to be intact herbicide. Liquid scintillation readings in counts per minute (cpm) were corrected for efficiency using an external standard and recorded as disintegrations per minute (dpms). The data are presented as percent of total applied ^{14}C-glyphosate or ^{14}C-imazapyr.

The study design was a randomized complete block, 4 replicates per treatment, and the study conducted twice. Data were subjected to analysis of variance to test for main effects and interactions. Means are presented with standard errors and were separated using Fisher's protected least significant difference. Because study by treatment interactions did not exist, the data from each study were pooled.

Results and Discussion

Light compensation point. The LCP of cogongrass as measured by the LiCor 6200 gas exchange system was 31.96 +/- 1.93 umol/m^2/s^1 ppfd. Based on this determination, growth rate of cogongrass at 15, 120, 600, and 1500 umol/m^2/s^1 of ambient light was compared. Cogongrass grown under 1% of ambient light lost biomass throughout the study, and by 15

weeks surviving plants were moribund (Table 5.1). Cogongrass grew relatively slowly at 3% of ambient light over 15 weeks of growth and only doubled biomass. Cogongrass growth at 50 and 100% of ambient light was approximately linear from 6 to 12 weeks, and leveled off over the final 3 weeks of the study. Photosynthetic photon flux density of 45 umol-m^{-2}-s^{-1} (3% of ambient light) is higher than the light compensation point, and 15 umol-m^{-2}-s^{-1} (1% of ambient light) is well below the LCP based on both LiCor gas-exchange determinations and growth rates at different light levels.

Plant fluorometry. Diuron, a herbicide which directly inhibits electron transport by attaching to the plastoquinone binding site in photosystem II, was included as a positive control and affected chlorophyll *a* fluorescence by 1 h after treatment (Table 5.2). Diuron reduced the peak-to-terminal fluorescence ratio by 55%, and reached unity by 2 h after treatment. Glyphosate affected chlorophyll *a* fluorescence 4 h after treatment, reducing the peak-to-terminal ratio by 43, 33, and 44% at 0.56, 1.12, and 2.24 kg/ha, respectively. This reduction continued and remained consistent throughout the duration of the study. The highest concentration of imazapyr reduced the ratio only at the 4 h measurement, and was equal to or higher than the control at all other concentrations and measurement times.

Herbicide efficacy. The I_{50}s for both glyphosate and imazapyr were highest at 1% of ambient light (Table 5.3). Phloem-mobile herbicides depend on photosynthesis and phloem-loading for translocation in the plant (Geiger and Bestman, 1990). Light levels below the LCP probably reduced photosynthesis, phloem-loading, and herbicide movement to the rhizomes. Glyphosate I_{50}s increased from 3 to 100% ambient light, and the I_{50} at 100% ambient light was 50% greater than at 3% ambient. Imazapyr was relatively unaffected by light levels above the LCP.

Herbicide absorption and translocation. The light level below the LCP (15 umol/m^2/s^1) severely limited translocation of either herbicide. Ninety-eight percent of the applied glyphosate and 73 % of the imazapyr was recovered in the leaf wash and treated leaf at this light intensity (Table 5.4). Only 0.6 and 0.5 % of the applied glyphosate and imazapyr, respectively, were recovered from the root/rhizome at the lowest light level.

At light levels above the LCP, ^{14}C-imazapyr recovered from the treated leaf decreased slightly as the light level increased. Less glyphosate than imazapyr was recovered from the treated leaf at light levels above the LCP and glyphosate recovered from the treated leaf decreased slightly at 600 and 1500 umol/m^2/s^1. Neither glyphosate nor imazapyr recovered from the shoots was affected by light levels above the LCP, but a greater amount of imazapyr than

glyphosate was recovered from the shoots based on significance of main effects in the ANOVA.

Movement of imazapyr into the root/rhizome was not dependent on light level. Glyphosate translocation into the root/rhizome was equal at the 120 and 600 umol/m^2/s^1 light levels, but increased 36% at the 1500 umol/m^2/s^1.

Based on these studies, glyphosate is more affected by high light intensity than is imazapyr. Glyphosate lowered the peak-to-terminal fluorescence ratio and the highest light treatment reduced inhibition of cogongrass regrowth after glyphosate application in the greenhouse. Maximum movement of glyphosate into the root/rhizome occurred at the highest light level. Translocation of imazapyr out of the treated leaf was dependent on light level, with higher light intensities increasing translocation. However, this did not translate into greater movement of imazapyr into the root/rhizome.

Although chlorophyll *a* fluorescence in cogongrass was affected by glyphosate, ambient light levels did not inhibit translocation. The lower efficacy of spring or summer applied glyphosate relative to autumn applied glyphosate observed in field situations and from high light in greenhouse experiments reported here is probably not due to high light intensity and subsequent acute phytoxicity. Greater long term control of cogongrass from autumn-applied glyphosate may be due to a longer rain-free period, or

increased translocation of carbohydrates and herbicide during the autumn months.

Approximately 25% of the applied ^{14}C-imazapyr was not recovered in either the plant tissue or leaf wash. Shaner (1988) reported 7% recovery of labelled imazapyr applied to cogongrass from the soil 4 DAT. Root exudation is probably responsible for the unrecovered imazapyr in this study.

Table 5.1. The influence of light intensity on cogongrass growth.

Light Level	Weeks After Replant				
	3	6	9	12	15
umol/m^2/s^1	- - - - - - - - - - - - g - - - - - - - - - - - -				
15	0.37 ±.03[1]	0.30 ±.04	0.30 ±.03	0.29 ± .04	0.09 ±.03
45	0.37 ±.03	0.36 ±.04	0.63 ±.09	0.75 ± .07	0.79 ±.12
750	0.37 ±.03	1.60 ±.16	4.81 ±.65	10.67 ±1.70	13.31 ±.96
1500	0.37 ±.03	2.28 ±.16	6.80 ±.56	13.77 ±1.66	18.32±1.32

[1] Mean total plant biomass followed by standard error.

Table 5.2. Effects of diuron, glyphosate, and imazapyr on chlorophyll *a* fluorescence in cogongrass.

Herb.	Rate	peak-to-terminal ratio (hours after treatment)					
		1	2	4	8	12	24
	(kg/ha)						
Diuron	2.24	1.27 a[a]	1.02 a	1.03 a	0.96 a	0.93 a	0.95 a
Glyph.	2.24	2.82 a	4.18 c	2.22 b	1.54 a	1.86 a	1.53 b
	1.12	2.45 a	2.36 b	2.63 b	1.92 b	2.25 a	1.66 b
	0.56	3.00 b	4.27 c	2.25 b	2.07 b	2.46 b	2.46 c
Imaz.	1.12	3.68 b	5.70 c	2.92 c	2.66 b	2.50 b	4.09 c
	0.56	4.27 b	5.96 c	8.43 c	2.89 b	4.38 c	3.20 c
	0.28	3.05 b	6.11 c	3.69 c	2.20 b	3.26 b	3.26 c
Control	--	2.83 b	5.84 c	3.93 c	2.73 b	3.21 b	2.92 c

[a] Means followed by a different letter are different at the 0.05 level of significance using Fisher's LSD.

Table 5.3. The influence of light intensity on the efficacy of glyphosate and imazapyr on cogongrass based on I_{50}s.

	Light Level ($umol/m^2/s^1$)			
Herbicide	15	45	750	1500
	---------- I_{50} ----------			
Glyphosate	0.17	0.10	0.12	0.15
R^2	0.48	0.64	0.54	0.93
Imazapyr	0.011	0.006	0.007	0.007
R^2	0.75	0.75	0.78	0.80

Note: I_{50} is the herbicide rate required to inhibit growth 50%.

Table 5.4. Absorption and translocation of ^{14}C-labelled glyphosate and imazapyr as affected by light intensity.

Section	Herbicide	Light Intensity (umol/m^2/s^1) 15	120	600	1500	Interaction[b]
		- - - - - - - % of applied ^{14}C - - - - - - -				
Leaf Wash	glyphosate	27.4 ± 0.96[a]	46.1 ± 4.00	59.3 ± 5.00	49.5 ± 3.00	0.10
	imazapyr	3.5 ± 1.07	4.4 ± 1.00	4.0 ± 1.00	6.3 ± 1.00	
Treated Leaf	glyphosate	70.6 ± 3.52	32.2 ± 2.00	26.0 ± 2.00	27.1 ± 3.00	NS
	imazapyr	69.4 ± 7.40	48.9 ± 3.00	44.6 ± 3.00	41.6 ± 3.00	
Shoots	glyphosate	5.2 ± 1.96	11.2 ± 1.60	11.7 ± 0.50	10.4 ± 1.80	NS
	imazapyr	3.1 ± 0.49	16.3 ± 2.20	18.4 ± 1.60	13.2 ± 2.40	
Root/Rhizome	glyphosate	0.6 ± 0.20	12.3 ± 2.00	12.2 ± 2.00	16.7 ± 4.00	0.10
	imazapyr	0.5 ± 0.05	11.2 ± 3.00	11.3 ± 2.00	9.8 ± 2.00	

[a] Means followed by standard errors.
[b] Herbicide by light interaction.

CHAPTER 6

SUMMARY AND CONCLUSIONS

This research has increased our understanding of cogongrass biology, physiology, plant-herbicide interactions, and management practices aimed at controlling cogongrass. However, the warnings of Pendleton in 1948 to completely eradicate cogongrass from the western hemisphere were generally ignored, and as a result, cogongrass will remain a permanent fixture in gulf states ecosystems. Cogongrass will also remain a severe problem in food and cash-crop production in tropical regions of the world. However, options for management of cogongrass-infested lands exist, which, if practiced diligently, offer a means of eradicating cogongrass from specific areas and allow a more competitive habitat for desirable plant species. Furthermore, by understanding the biology and physiology of cogongrass and environmental factors which affect these management practices, more effective and efficient long-term control will be achieved.

Glyphosate and imazapyr remain the most effective herbicides for cogongrass control. Fluazifop provided up to 50% inhibition of cogongrass but only for 6 months. Herbicides which are acutely phytotoxic, such as

glufosinate, were effective for only a short time before regrowth from rhizomes occurred. Glyphosate and imazapyr were more effective when applied in October or November than at any other time of the year. Numerous possibilities exist for the increased efficacy achieved with autumn applications. Lower light intensity in the fall may decrease acute phytotoxicity of herbicides. Limited rainfall in autumn may allow a longer rain-free period for the herbicides, thereby increasing herbicide absorption. An increase in carbohydrate, and thus herbicide, translocation to the rhizomes may occur during this time, and continued respiration and carbon loss from surviving rhizomes during the cool, dry, winter months may limit carbohydrate available for shoot production the following spring. Interference with normal nitrogen storage and remobilization mechanisms within the rhizomes may also be occurring, also limiting shoot production.

Discing stands of cogongrass was not effective for cogongrass control. Shallow tillage only fragmented rhizomes, causing only short-term growth reduction and subsequent strong shoot growth. A combination of discing and imazapyr treatments provided greater than 90% control. Removing old growth through burning and applying herbicide to new tissue may also be important. Herbicide interception by living plant tissue is maximized resulting in greater efficacy. Imazapyr applied to regrowth after burning was as

effective as imazapyr combined with discing.

Cogongrass rhizomes have tremendous regenerative potential and nearly every axillary bud along the length of the rhizome is capable of producing a shoot. Activity or dormancy of these buds was controlled primarily by an auxin-imposed apical dominance, and less directly by nitrogen availability. Rhizome segments from mature, natural stands of cogongrass were used for all studies reported herein. Previous published research has reported only limited shoot production from rhizomes. A possible explanation is that immature, greenhouse-propagated rhizomes were used in these studies, resulting in low shoot production.

Using plant growth regulators to break apical dominance in cogongrass was problematic. Soaking rhizomes directly in naptalam solutions increased bud activity, but plant growth regulators applied to foliage of whole plants did not affect growth, morphology, or bud dormancy. These results, and results from research reported in the literature, indicate that the PGRs studied here do not translocate well, if at all, in grasses.

An integrated management strategy utilizing all available methods of control is needed to effectively manage cogongrass. If the ecological niche is not filled with another plant species after control methods have been implemented, cogongrass will re-invade. Reliance on a single means of control will generally result in failure to

effectively manage cogongrass. Integrated management, including burning, tillage, mowing, chemical, and cultural control will increase the likelihood of cogongrass suppression. Burning removes old growth and dead biomass having two benefits. One, the rhizomes are forced to re-allocate starch storage reserves to produce new shoot growth, thereby weakening the rhizomes. Secondly, removal of the substantial biomass improves other management practices - tillage operations are more effective and, once regrowth occurs, greater herbicide coverage of actively growing tissue is achieved. Allowing regrowth after burning and tillage followed by a proven herbicide is the most effective management program. Above ground tissue is young and actively growing, the rhizomes have been weakened, and if timed correctly (October/November), the rhizomes may be strong photosynthetic sinks. After suppression of cogongrass, the establishment of desirable plant species is essential for long-term control of cogongrass. The strategy is to replace cogongrass, not just kill it. If a replacement plant species does not fill the niche occupied by cogongrass after suppression then cogongrass will simply refill the niche. In these studies, common hulled bermudagrass and hairy indigo in combination with glyphosate or imazapyr, respectively, grew vigorously and remained free of cogongrass for up to 2 years after seeding. Success of species establishment depended on tolerance to the herbicide

and soil type.

Future research which would improve management of cogongrass-infested lands includes evaluation and improvement of species for revegetation purposes. Desirable characteristics of revegetation species will include strong germination and emergence followed by quick canopy formation, a perennial habit or the ability to re-establish from seed each season, tolerance to the commonly-used herbicides for cogongrass control, and strong growth in a limited-input system.

Research which would increase our understanding of cogongrass biology and physiology includes determination of nitrogen storage and remobilization mechanisms. Successful sprouting of perennial plants depends on availability of nitrogen in the form of nitrate, amino acids, and vegetative storage proteins, and stored nitrogen is probably at least as important as stored carbohydrates for successful sprouting.

APPENDIX A

ACTIVITY OF PLANT GROWTH REGULATORS ON COGONGRASS USING VARIOUS APPLICATION METHODS

Introduction

Exogenous applications of plant growth regulators have the potential to change growth, development, and morphology of plants to which they are applied. Removing dominance exerted by the growing shoot apex in cogongrass (*Imperata cylindrica*) rhizomes leads to activation of previously dormant axillary buds along the length of the rhizome. Increasing axillary bud growth and development in cogongrass rhizomes may increase the shoot-to-rhizome ratio and provide greater avenues of chemical interception and subsequent translocation to rhizomes. Axillary buds which are active may also become stronger photosynthetic sinks and a lethal herbicide concentration in the buds would be more likely. The objective of these studies, therefore, was to evaluate various growth regulators and application methods for activity in cogongrass.

Materials and Methods

Naptalam, TIBA, ethephon, kinetin, and other growth regulators were evaluated by numerous applications methods. Rhizomes were soaked for 15 minutes in ethephon, giberillic

acid (GA), kinetin, and 3 nitroguanidine compounds (American Cyanimid) at concentrations of 0, 5, 50, and 500 mg/L in de-ionized water with 0.5% v/v Tween 20. The rhizomes were placed on trays, covered with 1 cm of perlite/vermiculite, and grown in a growth chamber at 16 h, 30 C days/8h, 25 C nights. Six-week-old cogongrass plants grown in 0.75 L pots were sub-irrigated with solutions of naptalam, GA, kinetin, ethephon, and 2,4-D at concentrations of 50 and 500 mg/L plus an untreated control. The same chemicals and concentrations, plus 1.0% v/v DyneAmic^{R} surfactant, were applied to foliage of 6-week-old cogongrass plants to run-off with a hand-held micro-applicator equipped with an 8001E nozzle tip. A potential interaction between nitrogen and ethephon was evaluated by growing cogongrass plants for 4 weeks in a perlite/vermiculite mix, and at 4 weeks sub-irrigating half of the plants with modified Hoagland's solution of either 10 or 100 mg/L nitrogen. Two weeks later, ethephon at 1.7, 3.4, 6.8, and 13.6 kg/ha was applied to foliage until run-off. Naptalam, GA, and ethephon were mixed with lanolin to form concentrations of 50, 500, and 5000 ug/g, and the mixture applied directly to individual nodes of freshly harvested apical rhizomes. The rhizomes were placed 3 to 4 cm diameter glass tubes on a bed of glass wool. The tubes were sealed and placed in a growth chamber. Naptalam and ethephon, at concentations of 100 and 1000 mg/L, were injected into nodes of freshly harvested apical

rhizomes. The 3 nitroguanidine compounds, naptalam, and ethephon at 500 and 5000 mg/L in de-ionized water with 1.0% v/v X-77 were swabbed onto 3 fully-extended leaves of 8-week-old cogongrass plants. Naptalam was further investigated by applying solutions of 100, 1,000, and 10,000 mg/L plus an untreated control, to 20 cm long apical rhizome segments with or without the apex intact. The solutions contained 0.5% v/v X-77 surfactant, and were applied with a hand-held micro-applicator equipped with an 8001E nozzle tip. A volume of 800 L/ha was oversprayed over each rhizome segment. Evaluation of all studies consisted of identifying morphological or coloration changes in whole plants, or counting shoot production from axillary buds of rhizomes.

Results and Discussion

Naptalam applied at 3 concentrations did not increase bud development relative to the untreated control when the apex was removed (Table A.1). The highest concentration of naptalam increased bud activity by 15% over the untreated control, and was the only treatment statistically different from the untreated control ($p<0.05$). As in other studies, activation of buds occurred when the apex was removed. The numerous other studies evaluating the effects of growth regulators on cogongrass growth and development produced negative results. Cogongrass growth and morphology was nearly completely unchanged when the growth regulators were applied to foliage. Red coloration of leaves was the most

apparent change in plants treated with high concentrations of ethephon or naptalam. When sub-irrigated with the growth regulators, 2,4-D, GA, and naptalam eventually killed the plants after approximately 4 weeks of exposure. Direct applications of growth regulators in lanolin or via injection into nodes did not increase axillary bud activity (data not shown).

Table A.1. Percent of rhizome nodes producing shoots as affected by apex and naptalam treatment.

	Naptalam concentration (mg/L)				
Apex	0.0	100	1000	10000	LSD (0.05)
	- - - - - - - - - - - - % - - - - - - - - - - - -				
present	11	18	18	26	8.8
removed	56	61	48	54	

APPENDIX B

THE INTERACTION OF MECHANICAL AND CHEMICAL CONTROL FOR THE MANAGEMENT OF COGONGRASS

Introduction

Mechanical or chemical control measures by themselves have proven insufficient for cogongrass (*Imperata cylindrica* (L.) Beauv.) management and numerous treatments of each is required for complete control. Only deep-plowing (>20 cm) has proven effective due to the inability of cogongrass rhizomes to produce a shoot from these depths (Wilcut et al., 1988a). In many areas deep plowing is not an option and disking or harrowing causes fragmentation of cogongrass rhizomes and may actually increase density of a cogongrass sward. Herbicides alone are unable to deliver a lethal dose to all buds on the rhizomes. Subsequent tillage operations have reduced rhizome dry weight (Willard et al., 1990), but cogongrass infestations remain. However, disking before and after imazapyr treatments inhibited cogongrass biomass more than imazapyr alone, although differences were not significant. Willard et al. (unpublished b), using sequential mowings and discings over 2 years and a single herbicide application, reported that combinations of either mowing or discing and imazapyr or glyphosate provided the best control, and that 2 mowings or 2 discings alone

provided a maximum of 73% control.

A more intensive scheme of discing and herbicides applied to the soil has not been compared to foliar treatments, discing only, or to chemical control alone. Therefore, the objective of this study was to evaluate the effects of discing alone and in combination with foliar and soil-applied herbicide treatments.

Materials and Methods

The study was initiated in July 1993 and August 1993. Both sites were flooded and work was terminated. In 1994, the study was restablished at site 1 and at site 2 on June 28 and 29, respectively. Site 1 was on a clay settling pond (approximately 85% clay) and site 2 was on a sand (80%) overburden in a bahiagrass/hairy indigo pasture. Studies at both sites received identical treatments. The study was being replicated in 1995/1996 at both sites.

The shoot biomass was burned off 1 or 2 days before the first treatments leaving fine ash and bare soil. Together with the controls of no discing and no herbicide, the study was a 4 X 3 factorial, randomized complete block design, with four replications. The factorial included 4 herbicide treatments and 3 discing treatments. The four herbicide treatments were as follows. Imazapyr at 0.84 kg/ha was

applied to the soil of designated plots on 29 June (one day after burning), representing the day 1 herbicide treatment. A second herbicide treatment consisted of imazapyr at 0.84 kg/ha applied to foliar regrowth on 14 August (44 DAB). The third herbicide treatment consisted of a split application of 0.42 kg/ha of imazapyr applied to foliar regrowth on 14 August 1994 and 30 September 1994 (44 and 90 DAB, respectively). The fourth treatment was the untreated control. The disking treatments were as follows. Two-thirds of the plots were disced on 29 June (1 DAB), representing treatment 1, and one-half of these plots received a second discing on 30 September, representing treatment 2. The third treatment was the untreated control. The timing of discing allowed time for foliar regrowth and herbicide translocation.

Results and Discussion

Excellent control of cogongrass was achieved by various treatments at 12 months after burning (Table B.1). A split application of imazapyr (0.42 + 0.42 kg/ha at 44 and 90 days after burning), a split application of imazapyr and 2 discings, and single and split applications of imazapyr without the benefit of discing caused a 90% inhibition of cogongrass growth. Similar results were achieved at both sites, the difference being that a single application of imazapyr to the soil without the benefit of incorporation achieved 90% control at site 2 and only 10% control at site 1. A single application (0.84 kg/ha) of imazapyr to the foliage at 45 days after burning provided the same control

as a split application of 0.22 kg/ha at day 45 and day 120 after burning except when a single discing was used. Imazapyr applied to the soil with or without incorporation, and discing alone provided a maximum of only 45% control at Akin 5/8, but up to 90% at site 2. The difference in efficacy at the two sites was likely due to soil differences. Clay soils have far greater particle surface area than sand and can bind herbicides tightly.

In summary, discing alone provided a maximum of 53% control (2 discings at site 2). Herbicide alone and in combination with 2 discings has maintained near 100% control at sites 1 and 2. However, applying imazapyr to foliage 44 days after discing resulted in less control than imazapyr applied without the benefit of discing. The 44-day timing may be too early, allowing dormant buds a chance to escape herbicide uptake. The 44- and 90-day split application may be late enough to allow more buds to become active and increase herbicide translocation.

Sollenberger et al. (1990) reported that removal of the apical meristem from stems of elephantgrass increased shoot production from nodes at 2 weeks after planting, but by 6 weeks after planting, the shoots per row, nodes with shoots, and shoot dry matter per stem had dropped to below those stems with the meristem intact. Cogongrass rhizomes may be reacting in a similar manner, producing a strong early flush of shoot growth after disking. When herbicides were applied

6 weeks later, shoot growth from these broken rhizomes may have died back, thus herbicide interception and subsequent translocation to rhizomes would be less than if the herbicides were applied to strong shoot growth of un-disked rhizomes. Thus, timing of herbicide applications after breaking apical dominance with tillage may be important. The fragmentation of rhizomes from leaf tissue may remove axillary buds from herbicide translocation and allow subsequent regrowth for these buds.

Table B.1. The influence of imazapyr and discing combinations on cogongrass control at Akin 5/8 and Payne Creek after burning or mowing (12 months after burning).

Discing Treatment	Location	Imazapyr Treatment (Days After Burn) none	1	44	44 & 90
		- - -	% control[a]	- - - -	
No disc	Site 1	0	10	98	90
	Site 2	0	90	100	100
One discing	Site 1	10	45	85	99
	Site 2	0	68	85	100
Two discings	Site 1	43	39	98	98
	Site 2	53	90	100	100

[a] Based on above-ground biomass collected from a 1 m^2 area. Biomass of untreated control = 337 g/m^2.

[b] To compare treatment effects within location LSD (0.05) values are 9 and 15 for Akin 5/8 and Payne Creek.

APPENDIX C

THE INFLUENCE OF SURFACTANTS ON IMAZAPYR APPLIED TO 3 PERENNIAL GRASSES

Introduction

Recent research has indicated that organo-silicate surfactants allow foliar applied herbicides to enter a plant leaf through the stomates because of dramatically reduced surface tension (Stevens, 1993). This is different from the mode-of-entry of other surfactants which tend to allow the entry of herbicides through the cuticle (Buick et al., 1993) A study was conducted to determine stomatal density differences in 3 perennial grasses, and to evaluate the efficacy of imazapyr/surfactant combinations applied to these grasses.

Materials and Methods

Stomatal density was determined on the abaxial and adaxial leaf surface from three different species using a 6% cellulose acetate solution. The cellulose acetate was applied to the leaf surface with a small paint brush, allowed to dry, and peeled off with a tweezers. The peel was mounted on a microscope slide and stomata counted under a microscope. Torpedograss (*Panicum repens* (L.)), cogongrass (*Imperata cylindrica* (L.) Beauv.) and johnsongrass (*Sorghum halepense (L.)*) were propagated in the greenhouse in 10 cm pots from one

inch rhizome segments. After 6 weeks, the plants were treated with imazapyr and one of three surfactants. Imazapyr was applied at 4 rates (0.10, 0.05, 0.03, and 0.015 kg ai/ha) with 0.25% V/V non-ionic surfactant, organo-silicate surfactant, or a methylated seed oil surfactant. Untreated and surfactant-alone treatments were included. Applications were made using a spray table delivering 20 gallons per acre at 35 psi.

Results and Discussion

Cogongrass had the highest abaxial stomatal density with an average of 221 stomates/mm^2 while johnsongrass and torpedograss had lower densities with 114 and 96 stomates/mm^2, respectively. Adaxial stomatal densities were shown to be significantly different between the three species as well. Johnsongrass had the lowest density with 85.5 stomates/mm^2, while cogongrass and torpedograss both had many more at 174 and 204 stomates/mm^2, respectively.

No species by surfactant interaction ($p>0.05$) existed. Averaged across all species, control provided by imazapyr and the three surfactants was equal except at the lowest concentration, where Sylgard (the organo-silicate) provided 58% control compared to 32 and 25% control for imazapyr with X-77 and Sun-It II, respectively (Table C.1). Based on this study, neither species nor stomatal density are important when choosing a surfactant to use with imazapyr. Only when low imazapyr concentrations are used does surfactant type become important.

Table C.1. The influence of surfactant type on efficacy of imazapyr at different rates.

Surfactant	Imazapyr Concentration Kg/ha 0.0	0.015	0.03	0.05	0.10
	% control				
Sylgard	0	58 a*	46 a	63 a	92 a
X-77	0	32 b	53 a	72 a	83 a
Sun-It II	0	25 b	56 a	68 a	92 a

* Means followed by different letters within columns are significantly different from each other based on Fisher's LSD at the 0.05 level.

APPENDIX D

SEASONAL CHANGES IN TOTAL NONSTRUCTURAL CARBOHYDRATE CONTENT IN COGONGRASS (IMPERATA CYLINDRICA (L.)) BEAUV.

Introduction

Understanding patterns of growth and source/sink relationships in development of perennials is needed for a comprehensive approach to perennial weed management. Nonstructural carbohydrates of a plant are reserves available for growth and respiration. The amount of total nonstructrual carbohydrates (TNC) in a plant is influenced by environment, taxonomy, anatomy, stress, phenology, and management.

Diurnal fluctuations in TNC have been documented (Greenfield and Smith, 1974). Nonstructural carbohydrate content of perennial plant parts may be used to determine translocation of photosynthate. If herbicides move with the translocation stream, determination of photosynthetic product movement may aid in the timing of herbicide application (Potter et al., 1986). Saldivar et al. (1992) reported that 'Florigraze' rhizoma peanut (*Arachis glabrata* (Benth.)) rhizomes contained low TNC concentrations from May to September and high concentrations of TNC in the autumn. Obrigawitch et al. (1990) found that late postemergence

applications (5 to 8 leaves) of the herbicide DPX-V9360 controlled johnsongrass (*Sorghum halepense*) better than early postemergence (2 to 5 leaves) treatments. The authors attributed greater efficacy to the increased interception of herbicide due to greater foliage present late-postemergence. Sprouting from rhizomes also occurred after early postemergence treatments. In northern India, allocation of nutrients and assimilate to cogongrass rhizomes increased rapidly from November to January, (immediately before the hot dry season) and was very low from May through August, which coincides with the warm rainy season. Tanner et al. (1992) reported fall treatments of glyphosate provided greater control than spring or summer treatments.

Environmental conditions that promote movement of assimilate to the roots and rhizomes also favor herbicide translocation to these parts (Harker and Dekker, 1988). Total nonstructural carbohydrate concentration in roots of prickly-pear was lowest on 1 July and increased after fruit drop in September (Potter et al., 1986). Replenishment occurred from early autumn to midwinter. The authors suggested that photosynthetic rates may be high in autumn through midwinter, and that the most effective time for herbicide application would be August through March. Age of individual plants may also play a role in herbicide translocation. In a glasshouse study, dalapon at 8.0 kg ai ha^{-1} completely killed foliage at the one-leaf shoot stage,

achieved partial kill at the 4-leaf stage, and killed old leaves, tips, and mid-regions of younger leaves (Lee, 1986). Glyphosate at 1.0 kg ai/ha achieved 75% kill of shoots at the 4 and 6 to 7-leaf stages. Dalapon and glyphosate caused decay of primary rhizomes after one month when applied at the 1-leaf stage. At the 4-leaf stage, dalapon caused decay of only a few secondary buds and rhizomes, whereas glyphosate caused the decay of primary rhizomes in fifty percent of the treated plants. At the 6 to 7-leaf stage, dalapon had little effect on primary, secondary, or tertiary rhizomes. Glyphosate turned primary rhizomes black and soft, secondary rhizomes decayed at the shoot apices and on most rhizomes. Glyphosate caused complete decay in tertiary rhizomes when applied at the 6 to 7-leaf stage. The objective of this study was to evaluate seasonal changes in TNC content in cogongrass.

Materials and Methods

Cogongrass rhizome and shoot tissue was harvested from the site 1 clay settling pond 4 miles southeast of Mulberry in Polk County, Florida, from February 1993 to February 1995. Plant samples were stored on ice during transfer to the lab, where they were washed, heated at 105 C for 90 minutes followed by 70 C for 48 hours. The samples were ground through a 1 mm screen and stored in a freezer at -10 C. Total nonstructural carbohydrate analysis was performed according to Smith (1969) as modified by Christensen et al.

(1982). Amyloglucosidase and invertase are used to break down starch and oligosaccharides and sugar monomers are quantified spectrophotometrically after reaction with a copper reagent. A minimum of 6 samples was analyzed for each sampling date.

Results and Discussion

Total nonstructural carbohydrate content of rhizomes followed similar trends in 1993 and 1994 except for the May sampling date (Figure A.4). Total nonstructural carbohydrate content was generally higher in 1993 than in 1994. In 1993, TNC content peaked at 40 and 45 $mg\text{-}g^{-1}$ in February and May, respectively. TNC content remained generally constant at 30 $mg\text{-}g^{-1}$ during other times of the year, until November when TNC dropped to 25 $mg\text{-}g^{-1}$ before climbing sharply in December and January. In 1994 a peak of 37 $mg\text{-}g^{-1}$ TNC did not occur until March, and then dropped from the 30 $mg\text{-}g^{-1}$ level in October to a low of 9 $mg\text{-}g^{-1}$ in November before returning to 30 $mg\text{-}g^{-1}$ in December. The very low TNC level in November 1994 may be an anomoly due to overheating the sample during drying or other experimental error. However, the trend of a precipitous drop in TNC content is evident in 1993 as well. These results are similar to those of Potter et al. (1986) in prickly pear cactus, who reported high TNC levels in basal crowns and roots from November through April, with generally lower and constant levels from May to August. The TNC concentrations

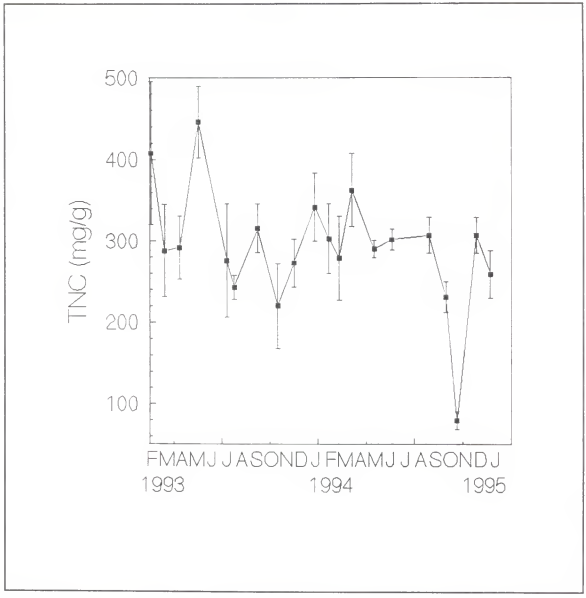

Figure D.1. Total nonstructural carbohydrate content in cogongrass rhizomes at different times of the year.

in cogongrass also agree with assimilate and nutrient movement in cogongrass reported by Saxena and Ramakrishan (1983) in northern India. They reported a greater allocation to rhizomes from November to January immediately before the dry, slow growth season.

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BIOGRAPHICAL SKETCH

James Frank Gaffney was born January 12, 1962, in Redwood Falls, Minnesota. He graduated from Redwood Falls High School in June 1980, and entered the University of Minnesota at St. Paul the following October. He received his bachelor's degree in agriculture business management in 1985.

From 1985 until 1989, he served in the United States Peace Corps in Cameroon, Central Africa, working at an agricultural vocational school. In Cameroon, he met his wife, Marie Rachel Meyembe, and was married on March 31, 1988.

Upon his return from Cameroon, Jim worked in the soil science/water quality lab at the University of Minnesota for one year, and entered a Master's program in plant science at South Dakota State University. He completed his M.S. in 1993 and enrolled at the University of Florida in January 1993 to pursue a doctoral degree in agronomy, specializing in weed science.

In 1994, Jim and Marie added a third member to their family by adopting a son, Ngassang Frank Gaffney.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Donn G. Shilling
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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